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From: Steven Koonin <steven.koonin@gmail.com>
Sent: Tuesday, April 29, 2025 2:23 PM
To: Roy Spencer
Cc: Ross McKittrick; Judith Curry; Travis Fisher; John Christy
Subject: Re: Process question?

Those are exactly the people we want to confront. Doing so proactively is an overt symbol of confidence/strength.

Steven E. Koonin

On Apr 29, 2025, at 11:10, Roy Spencer <roywspencer@hotmail.com> wrote:

An NAS review will be entirely determined by who they choose as reviewers. Who do you think they will choose? John and I and Pielke Sr went through this years ago and we were not only shut down by the majority (no doubt as required by the sponsoring agency) but as I recall the final document had changes we had not approved. I don't trust NAS any more than I trust the IPCC. Judy's suggestion of a House bipartisan panel is the same as Pielke Jrs' suggestion from years ago.

Sent from my Verizon, Samsung Galaxy smartphone

----- Original message -----

From: Steven Koonin <steven.koonin@gmail.com>
Date: 4/29/25 12:12 PM (GMT-06:00)
To: Ross McKittrick <ross.mckittrick@gmail.com>, Judith Curry <curry.judith@gmail.com>
Cc: Travis Fisher <travis.scott.fisher@gmail.com>, John Christy <climateman60@gmail.com>, Roy Spencer <roywspencer@hotmail.com>
Subject: Re: Process question?

The field suffers badly from a lack of serious engagement between the consensus and the realists. A formal NASEM review, followed by a response from us, would be a substantial step toward promoting that engagement. It would have much more substance and credibility than our responses to the random public comments.

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Steven Koonin

From: Ross McKittrick <ross.mckittrick@gmail.com>

Sent: Tuesday, April 29, 2025 10:07:13 AM

To: Judith Curry <curry.judith@gmail.com>

Cc: Steven Koonin <steven.koonin@gmail.com>; Travis Fisher <travis.scott.fisher@gmail.com>; John Christy <climateman60@gmail.com>; Roy Spencer <roywspencer@hotmail.com>

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On Tue, Apr 29, 2025 at 8:39 AM Steven Koonin <steven.koonin@gmail.com> wrote:

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Steven E. Koonin

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<http://www.cfanclimate.net>

From: Roy Spencer <roywspencer@hotmail.com>
Sent: Tuesday, April 29, 2025 2:11 PM
To: Steven Koonin; Ross McKitrick; Judith Curry
Cc: Travis Fisher; John Christy
Subject: RE: Process question?

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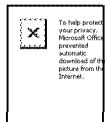
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Cc: Steven Koonin <steven.koonin@gmail.com>; Travis Fisher <travis.scott.fisher@gmail.com>; John Christy <climatemanager60@gmail.com>; Roy Spencer <roywspencer@hotmail.com>
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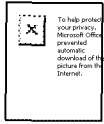
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Cc: Steven Koonin; Travis Fisher; John Christy; Roy Spencer
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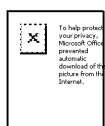
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From: Travis Fisher <travis.scott.fisher@gmail.com>
Sent: Tuesday, April 29, 2025 1:03 PM
To: Judith Curry
Cc: Steven Koonin; Ross McKittrick; John Christy; Roy Spencer
Subject: Re: Process question?

If the current plan holds, we will receive more comments than we can possibly handle through the comment process associated to the proposed rule at EPA. If you all are interested, we will likely need help in addressing those comments.

I could also imagine a more thorough and longer-term approach to something like the next version of the National Climate Assessment. In that case, I would support a transparent, bipartisan process.

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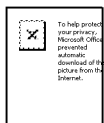
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From: Ross McKittrick [ross.mckittrick@gmail.com]
Sent: 4/19/2025 11:35:44 PM
To: Judith Curry [curry.judith@gmail.com]
CC: Steven Koonin [steven.koonin@gmail.com]; Travis Fisher [travis.scott.fisher@gmail.com]; Roy Spencer [roywspencer@hotmail.com]; John Christy [climateman60@gmail.com]
Subject: Re: outline for a slimmed down report
Attachments: ~WRD0001.jpg

I can put 10 together quickly, global greening, I have all the notes.

On Sat, Apr 19, 2025 at 7:12 PM Judith Curry <curry.judith@gmail.com> wrote:
also, sea level is done, awaiting footnotes

On Sat, Apr 19, 2025 at 1:36 PM Steven Koonin <steven.koonin@gmail.com> wrote:
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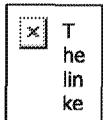
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To help protect
your privacy,
Microsoft Office
prevented
automatic
download of this
picture from the
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I have done heat/cold mortality (working on foot notes, will post shortly

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From: Steven Koonin <steven.koonin@gmail.com>
Sent: Saturday, April 19, 2025 4:37 PM
To: 'Judith Curry'; 'Ross McKittrick'
Cc: 'Travis Fisher'; 'Roy Spencer'; 'John Christy'
Subject: RE: outline for a slimmed down report
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From: Ross McKittrick <ross.mckitrick@gmail.com>
Sent: Monday, April 14, 2025 11:25 AM
To: John Christy
Cc: Steve Koonin; Roy Spencer
Subject: Re: Section 2.1.2 Forecast Skill

This info looks fine. For this section I was also hoping you could just provide a general description of the tools we currently have for forecasting extreme weather, e.g. NHC forecasts, flood warnings, tornado warning systems, etc. The idea is that whether weather is dangerous or not depends on our ability to predict and prepare for bad events. The information you present shows that this ability is improving and the mortality risk is declining. But it might be helpful to have a couple of paragraphs to tell readers what systems are in place for extreme weather prediction and risk management.

Ross

On Mon, Apr 14, 2025 at 11:12 AM John Christy <climateman60@gmail.com> wrote:

Ross

The aspect of improving forecasting skill as a part of an EF reconsideration is new to me. I started looking at some things, but had to come back to the astonishing drop in weather-related deaths of which enhanced forecast skill would be only a bit player. Before I go down a rabbit hole, this is what I wrote. It's not long (and shouldn't be). Is any of this useful?

John C.

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Sent: 4/14/2025 3:12:38 PM
To: Ross McKittrick [ross.mckittrick@gmail.com]; Steve Koonin [steven.koonin@gmail.com]; Roy Spencer [roywspencer@hotmail.com]
Subject: Section 2.1.2 Forecast Skill
Attachments: [2.1.2]Apr14.[JC].docx

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CONFIDENTIAL
FOR DISCUSSION PURPOSES ONLY

**Current Scientific Understanding of US Greenhouse Gas Emissions from Motor
Vehicles as an Endangerment to US Citizens**

Section 2.1.2

Forecasting systems for extreme weather [JC]

Weather and climate threats to human life often relate to temperature and precipitation extremes (i.e., hottest, coldest, wettest, driest for given day-lengths) as well as other high-impact events (typically wind-related; hurricanes, tornadoes, wildfires, etc.). In addition, these extremes often determine the survival limits of flora (including agricultural crops) and fauna (including sources of protein for humans). Thus, it is prudent to examine whether changes in these surface extremes have been seen [see 2.2] but here we shall touch on the improvements in resilience with some simple metrics.

The ability to reduce weather-related threats to human survival accelerated in the 20th century as seen in the dramatic drop in deathrates due to such threats (Fig. 2.1.2a). There are many aspects of human progress that explain this reduction such as, agricultural mechanization and irrigation, development of heartier plant and animal species, more robust infrastructure, electrification, transportation that delivers goods and services to meet demand, medical advances, ubiquitous real-time communication devices, etc. One component of this threat-reduction is the improving skill of weather forecasts, allowing the population to be forewarned of potentially dangerous weather and thus seek protection. South Asia, for example, because of extensive satellite coverage, will not again be surprised by land-falling cyclones such as Bhola in 1970 that killed between 300,000 and 500,000 people.

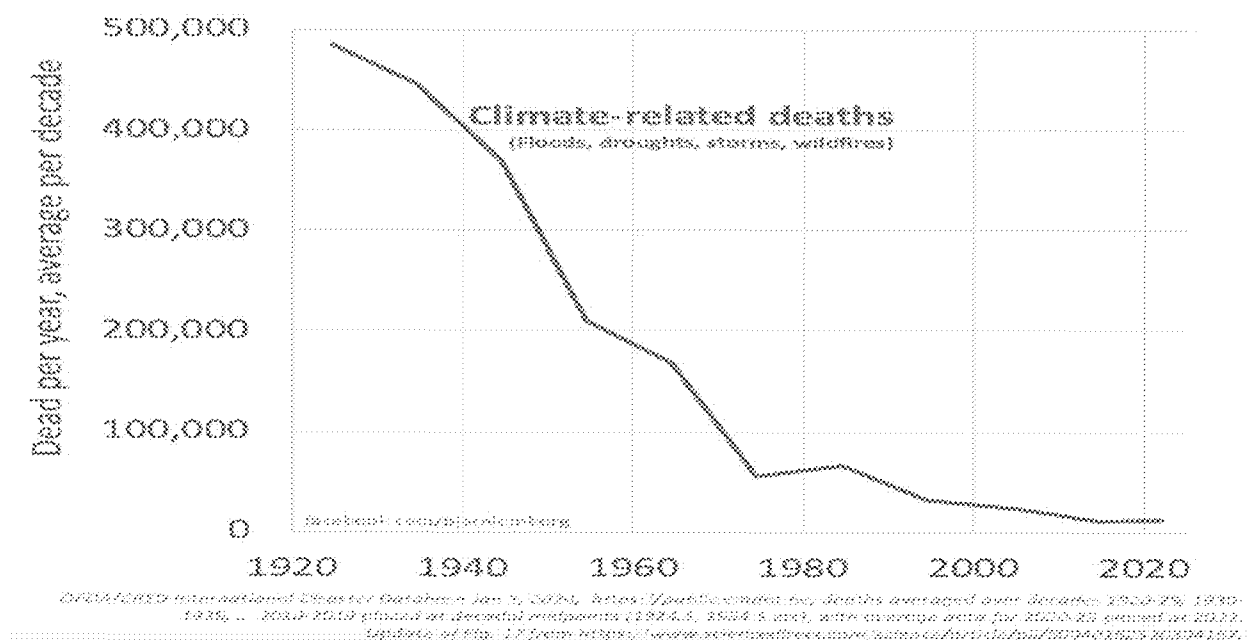


Figure 2.1.2a Climate related deaths as decadal averages (last data point represents 2020-24). OFDA/CREED International Database.

In the US, the forecasting skill of the National Weather Service and other service providers has made tremendous strides in the past 50 years. A recent example was the well-forecasted heatwave, unprecedented in last 150 years, in the Pacific NW in late June 2021 (Mass et al. 2024) for which residents and infrastructure-managers could prepare. In another example, hurricane

forecasts for US landfalls indicate the accuracy of a modern 5-day forecast exceeds the skill of a 2-day forecast from 1970 (Alley et al. 2019).

However, other metrics which represent decisive influences on the reduction of weather-related deaths such as increases in global grain production, access to electricity, and general wealth and longevity make it difficult to quantify the improvements due to increasing forecast skill alone. Lazo et al. 2009 estimated that the overall benefit to US residents of general weather forecasts was \$31.5B at that time. Finally, the likelihood that Artificial Intelligence applications will provide targeted information that is more precise in both space and time and communicated through personal devices suggests even greater protection for US citizens in the coming years. (Lam et al. 2023).

Alley, R.B., K.A. Emanuel and F. Zhang, 2019. Science. 363, no. 6425 342-344.

Lazo, J.K., R.E. Morss, and J.L. Demuth, 2009. Bull. Am. Meteor. Soc., 90, 785.

Lam, R. et al., Learning skillful medium-range global weather forecasting. Science 382, 1416-1421 (2023). DOI: [10.1126/science.adi2336](https://doi.org/10.1126/science.adi2336)

From: Roy Spencer <roywspencer@hotmail.com>
Sent: Tuesday, April 15, 2025 4:56 AM
To: John Christy
Cc: Ross McKittrick; Steve Koonin
Subject: Re: [2.2.2 and 2.2.3]Apr14[JC] Figs. Heat/Cold waves

Those look good to me.

-Roy

From: John Christy <climateman60@gmail.com>
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Cc: Ross McKittrick <ross.mckittrick@gmail.com>; Steve Koonin <steven.koonin@gmail.com>
Subject: Re: [2.2.2 and 2.2.3]Apr14[JC] Figs. Heat/Cold waves

Roy

See attached.

John C.

On Mon, Apr 14, 2025 at 10:54 AM Roy Spencer <roywspencer@hotmail.com> wrote:
John:

My preference would be to leave out the regional results in the 1st and 3rd plots... graphs are too busy. Just keep the USA48 results.

-Roy

From: John Christy <climateman60@gmail.com>
Sent: Monday, April 14, 2025 10:45 AM
To: Ross McKittrick <ross.mckittrick@gmail.com>; Steve Koonin <steven.koonin@gmail.com>; Roy Spencer <roywspencer@hotmail.com>
Subject: [2.2.2 and 2.2.3]Apr14[JC] Figs. Heat/Cold waves

Roy

I'm sending these figures that now use 1211 USHCN stations. I'm not inserting these into the document as they are for consideration. The data can be displayed however we would like. The 20-year running averages give a better climate picture I think. I believe one of the complaints of NCA5 was that the NCA5 group did no research on their own, whereas this would show we had the expertise to do the actual investigation.

In some way the point should be made that the temperature extremes are 1+ orders of magnitude greater than the small rise due to GHGs, so they will still occur. The US has not seen the weather patterns that created the

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Ross.

I assume you will hold the "Master" that combines all sections once each author is comfortable with letting text/figures be included?

John C.

From: John Christy [climateman60@gmail.com]
Sent: 4/14/2025 10:20:31 PM
To: Roy Spencer [roywspencer@hotmail.com]
CC: Ross McKittrick [ross.mckittrick@gmail.com]; Steve Koonin [steven.koonin@gmail.com]
Subject: Re: [2.2.2 and 2.2.3]Apr14[JC] Figs. Heat/Cold waves
Attachments: CONUS_HtWvs.png; CONUS_CldWvs.png

Roy

See attached.

John C.

On Mon, Apr 14, 2025 at 10:54 AM Roy Spencer <roywspencer@hotmail.com> wrote:

John:

My preference would be to leave out the regional results in the 1st and 3rd plots... graphs are too busy. Just keep the USA48 results.

-Roy

From: John Christy <climateman60@gmail.com>
Sent: Monday, April 14, 2025 10:45 AM
To: Ross McKittrick <ross.mckittrick@gmail.com>; Steve Koonin <steven.koonin@gmail.com>; Roy Spencer <roywspencer@hotmail.com>
Subject: [2.2.2 and 2.2.3]Apr14[JC] Figs. Heat/Cold waves

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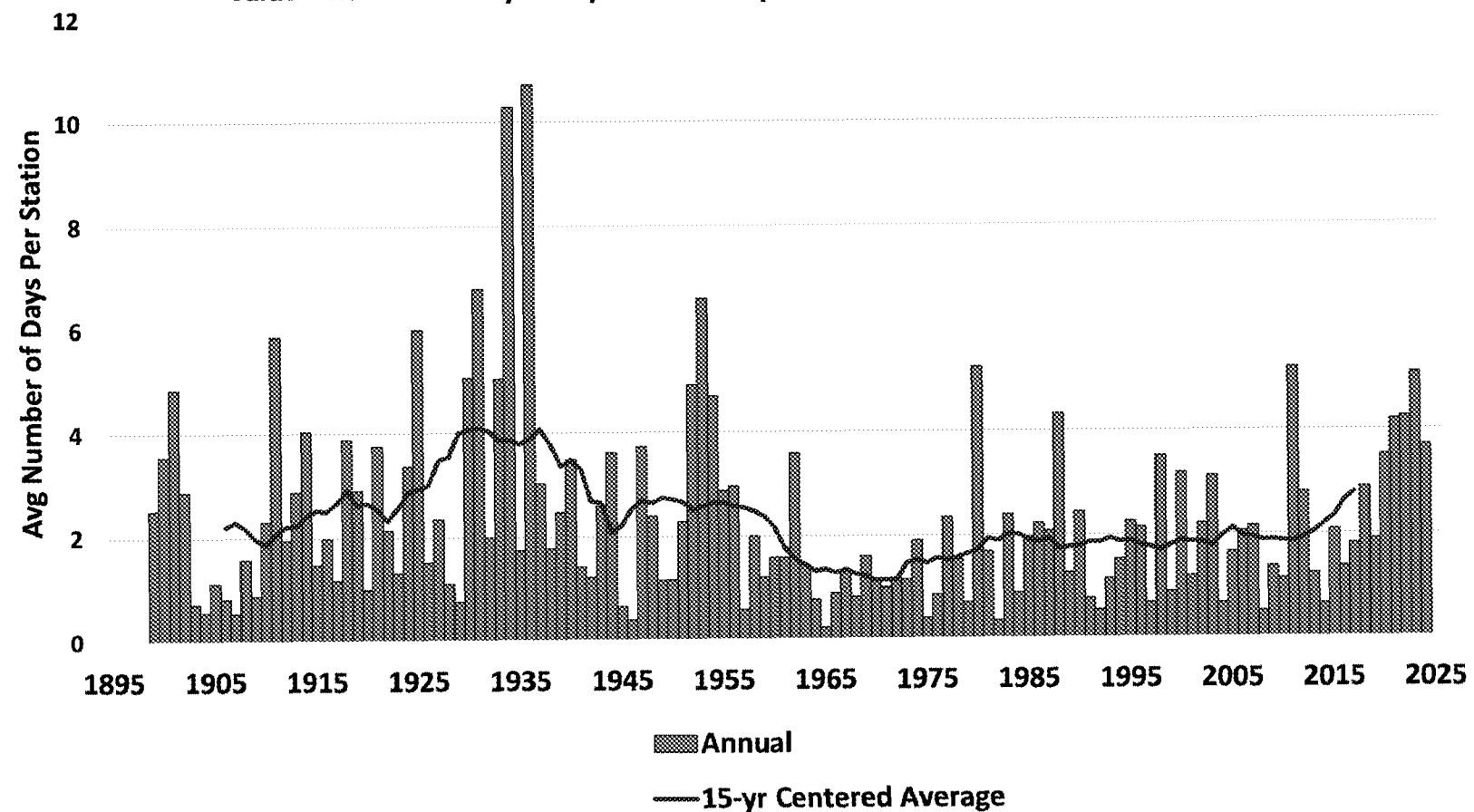
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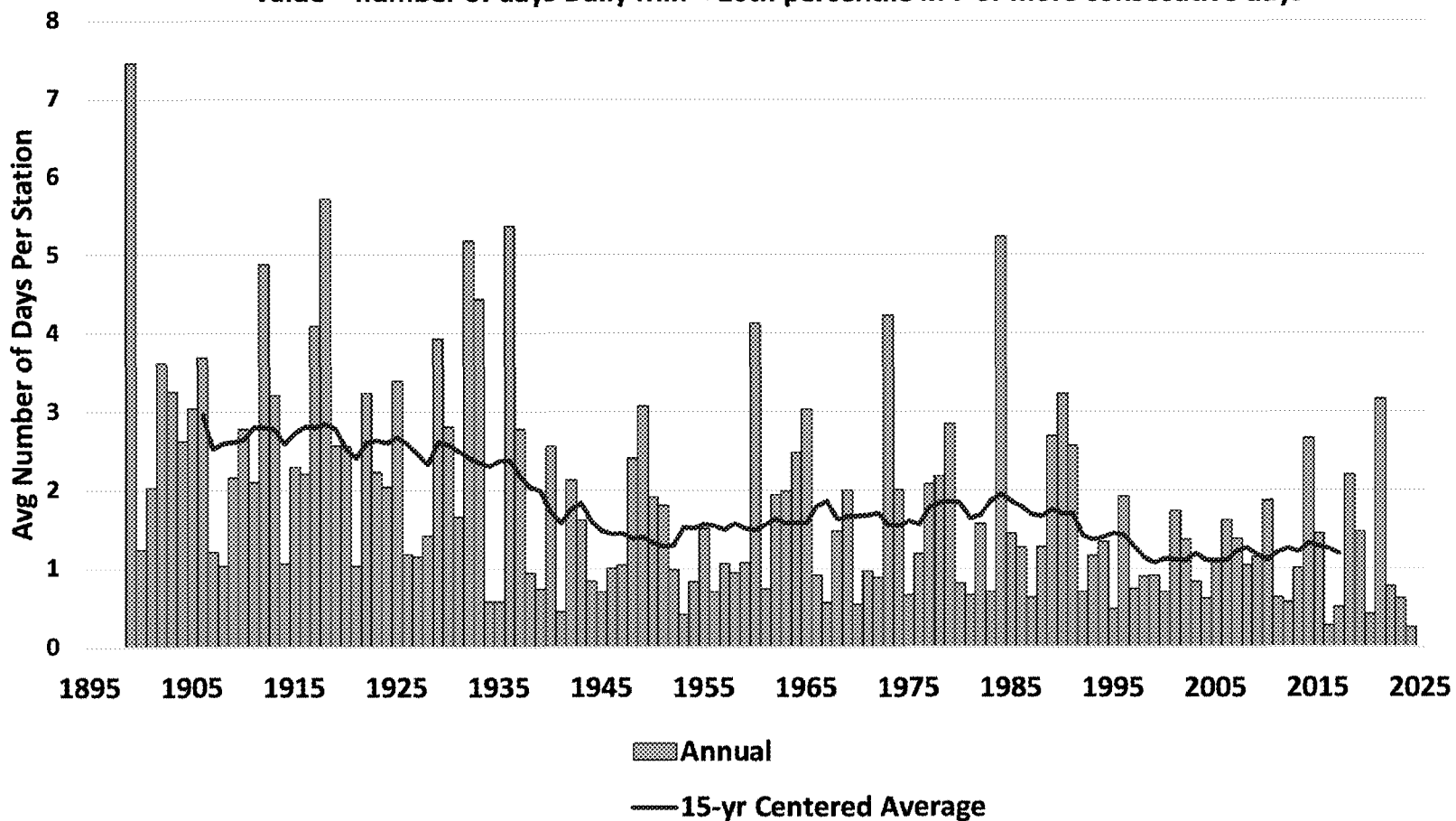
John C.

CONUS Average of 1211 USHCN Stations Heatwave Days Per Year
Value = number of days Daily Max > 90th percentile in 7 or more consecutive days



CONUS Average of 1211 USHCN Stations Coldwave Days Per Year

Value = number of days Daily Min < 10th percentile in 7 or more consecutive days



From: Roy Spencer <roywspencer@hotmail.com>
Sent: Monday, April 14, 2025 11:54 AM
To: John Christy; Ross McKittrick; Steve Koonin
Subject: Re: [2.2.2 and 2.2.3]Apr14[JC] Figs. Heat/Cold waves

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From: John Christy [climateman60@gmail.com]
Sent: 4/14/2025 3:45:36 PM
To: Ross McKittrick [ross.mckittrick@gmail.com]; Steve Koonin [steven.koonin@gmail.com]; Roy Spencer [roywspencer@hotmail.com]
Subject: [2.2.2 and 2.2.3]Apr14[JC] Figs. Heat/Cold waves
Attachments: [2.2.2_2.2.3]Apr14[JC].docx

Roy

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Ross.

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John C.

Section 2.2.2 Heatwaves

IPCC and other official assessments [RM]

Text text text.

Other scientific sources [RS]

Text text text.

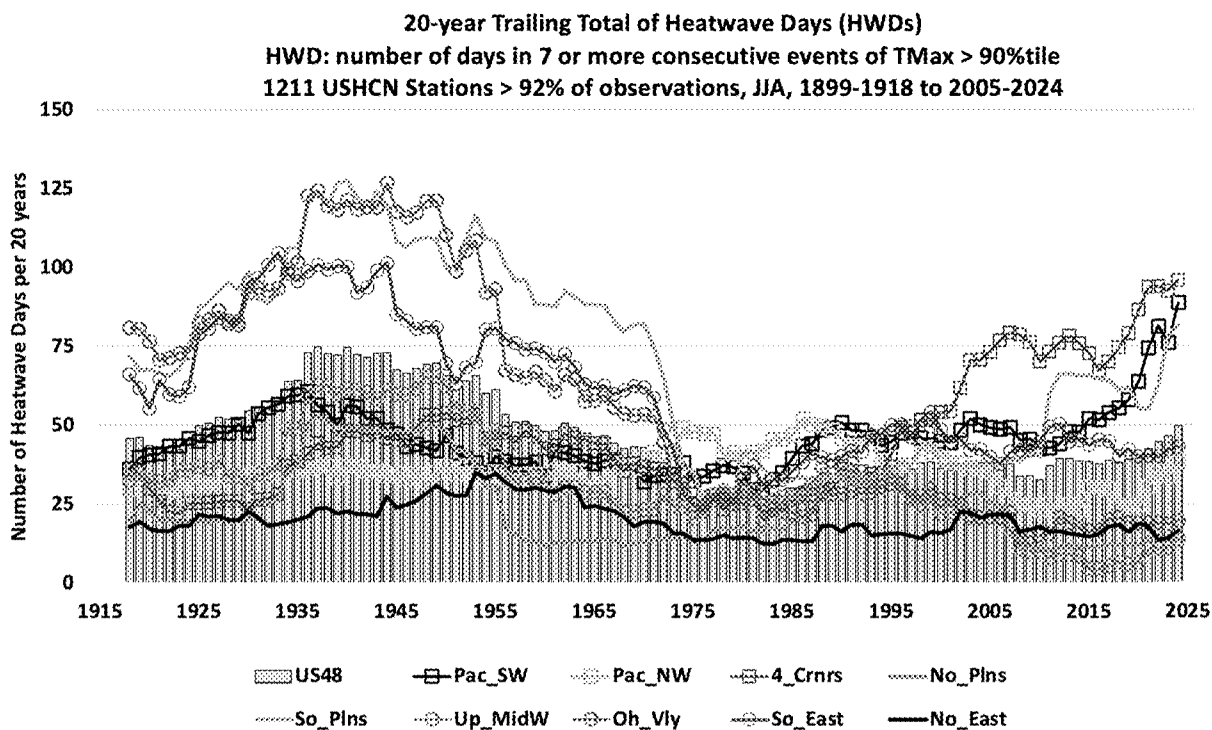


Figure Number of days in heat waves over 20-year running periods, 1899-1918 to 2005-2024 in the CONUS. Days above 90th percentile temperature in consecutive days of at least 7 days in length.

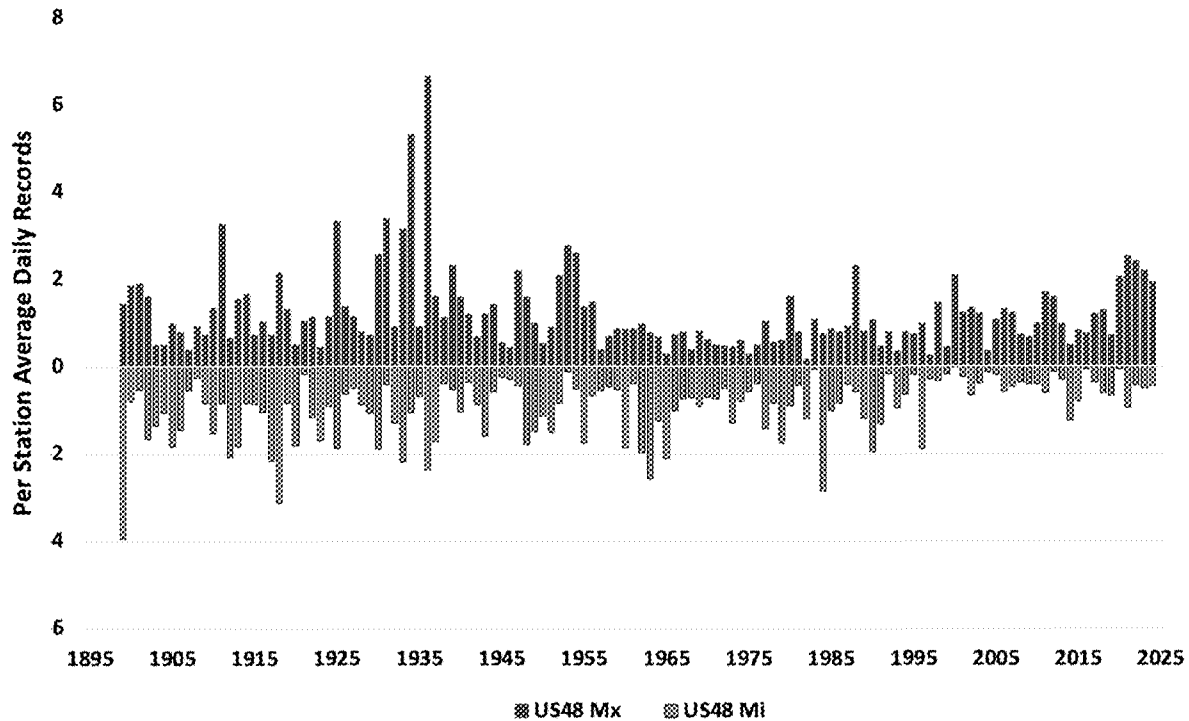


Figure. Conterminous US station-average of number of daily high (153 day of May-Sep) and low (122 days of Dec-Mar) temperature records in each year. The expected value for any year for May-Sep (Dec-Mar) would be $1.21 = 153/126$ ($0.97 = 122/126$).

2.2.3 Blizzards and extreme cold

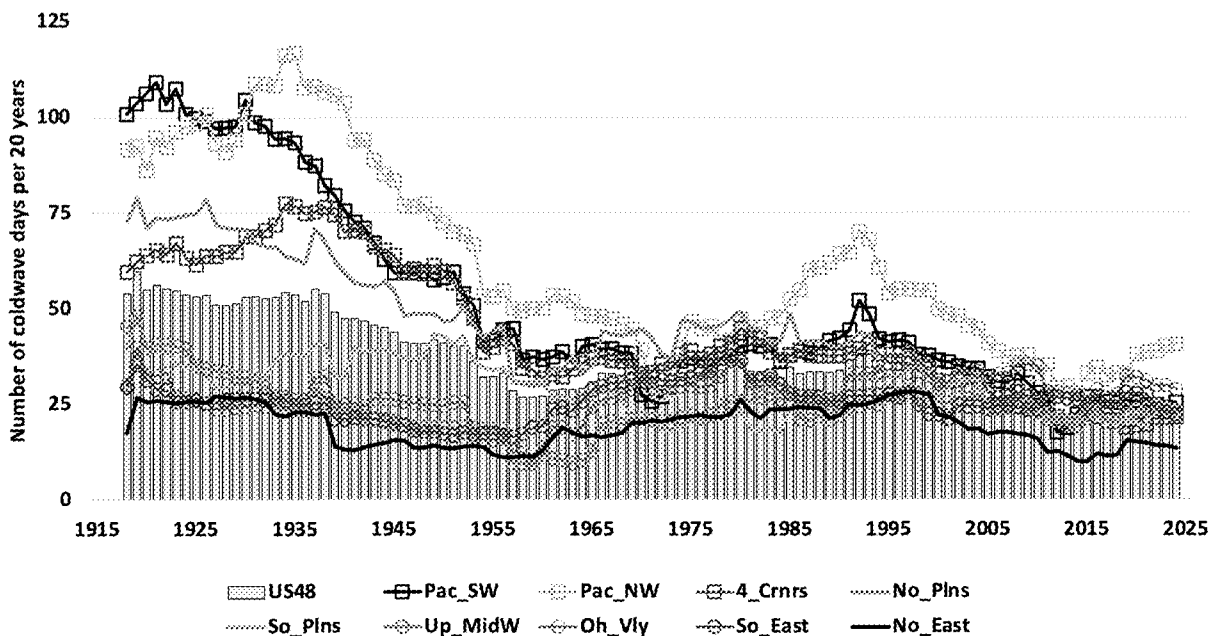


Figure. Number of days in cold waves for 20-year periods, 1899-1918 to 2005-2024. Days below 10th percentile temperature in consecutive days of at least 7 days in length.

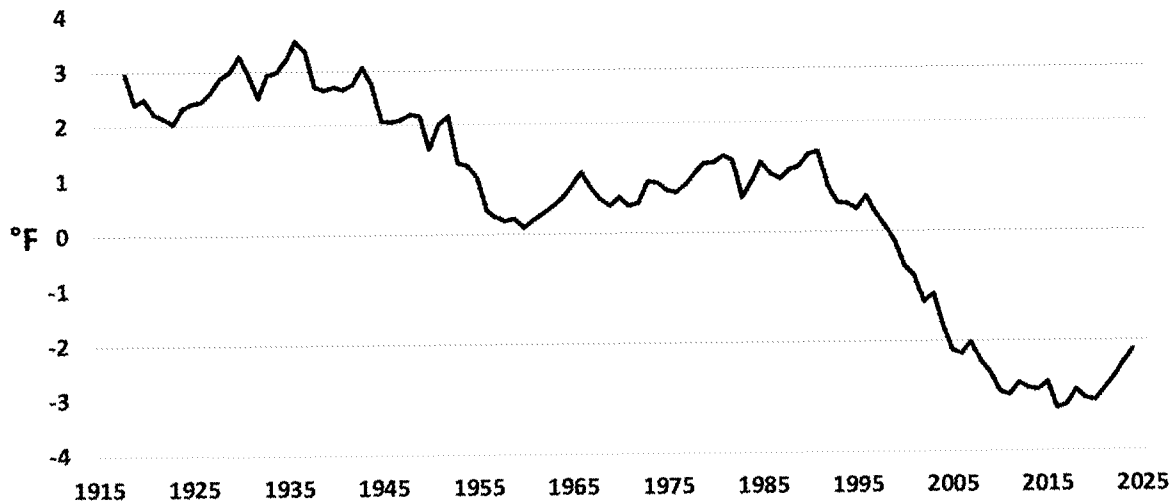


Figure. Twenty-year running average of annual station differences between hottest and coldest temperature (CONUS from 1211 USHCN stations, 1899-1918 to 2005-2024). Both hottest and coldest temperature temperatures have become milder in the CONUS, though the coldest temperature extremes have warmed more than the hottest days have cooled.

From: John Christy [climateman60@gmail.com]
Sent: 4/17/2025 3:19:45 PM
To: Ross McKittrick [ross.mckittrick@gmail.com]; Roy Spencer [roywspencer@hotmail.com]; Steve Koonin [steven.koonin@gmail.com]
Subject: [1.2]Apr17[JC] and question
Attachments: [1.2]Apr17[JC].docx

Ross

1. I'm assuming you are keeping the Master. I've found my MS version must be a little different and gets confused on the structure of the document. Attached is my v1 of 1.2.

2. Do you need updates of the deep atmospheric temperatures through 2024 for new plots?

I'm using separate email threads so the subject line is clear as to what is in the email.

John C.

17 April 2025

1.2 How Climate Conditions are Measured [JC]

The climate system consists of the global deep atmosphere, the full ocean and the upper layers of the land and ice surface - reservoirs of energy which are able to interact with each other on times scales up to centuries. Most climate concerns however are related to what happens at the surface where we live and grow our food. The directly-measured surface climate metrics that provide the longest record for analysis (generally since the late 19th century) are daily values of precipitation, i.e., rain and snow, and near-surface air temperature, i.e., the hottest and coldest values occurring in each 24-hour period (IPCC AR6 2.3.1.1.3 and 2.3.1.3.4). The amount of water vapor (humidity) in the atmosphere is also an important metric for determining heat content (IPCC AR6 2.3.1.3.2 and 2.3.1.3.3).

The number of weather patterns experienced by the natural climate system is essentially infinite so that a very long period of measurements is desirable to quantify natural variability with confidence [see 1.3]. However, with only 130+ years of quasi-large-scale surface observations we are presented with a fairly small time-sample of Earth's history from which to determine, for example, metrics such as extreme values or to assess whether changes may be related to increasing GHGs rather than natural variability. A critical question to address is whether the climate variations of the last 130 years (a very thin slice of climate history) represent a useful sample of all of the possible natural variations so that claims of significance (e.g., due to GHG forcing) may be made when a recent change is observed. Then, to this temporal impediment is the shortfall of spatial sampling with most of the global surface - even to this day - still unmonitored by *in situ* instrumentation which adds to the uncertainty of the values through time.

Surface temperature measurements are confounded by several heterogeneities in the record such as station relocations, instrument changes, instrument drifts/malfunctions, station closures, encroachment of temperature-altering infrastructure such as buildings, streets, deforestation, etc. All of these influences reduce confidence that the long-term, unadjusted values are stable enough for assessing small changes in the background climate. These non-climate temperature impacts, especially changes in the local environment, are significant and attempts to quantify their magnitudes are numerous (IPCC AR6 1.5.1, 2.3.1.1.3).

With the advent of vertical profiling techniques in the 20th century (balloons for the atmosphere, bathythermographs for the ocean, bore-holes for land and ice caps), a more comprehensive picture of the 3-dimensional climate system was made possible (IPCC AR6 2.3.1.2, 2.3.3.1., 2.3.1.1.2). These measurements are of critical importance because the fundamental metric for understanding changes caused by enhanced greenhouse gas (GHG) forcing is the number of heat units (joules) residing in the reservoirs of the climate system (atmosphere, ocean, near-surface land/ice) and how that number might be changing. The theory of GHG forcing indicates the number of joules should be increasing, primarily detected as rising temperatures in the full ocean and lower atmosphere (sfc to ~12km). From the 1970s

satellites have provided global coverage for the first-time of several climate metrics, including clouds, snow and ice cover, water vapor, aerosols, winds, incoming and outgoing energy, and the deep atmospheric temperature – the latter a key for detecting GHG influences as mentioned (IPCC AR6 2.3.1.2, 2.3.1.3.3).

US observations are also available of high-impact weather events which have been systematically recorded for such phenomena as hurricanes (since 1850 for Atlantic storms), strong tornadoes (since 1950s), floods, droughts, etc. (IPCC AR6 11.4-11.7). In addition to these relatively rapid events are changes that are slow such as sea level rise and ocean pH changes (IPCC AR6 9.6, 12.4.8, 3.6.2). Snow and sea ice extents have particular significance as indicators of climate change with measurements from satellites providing global coverage since 1978 to supplement surface and aircraft measurements beginning in earlier years (IPCC AR6 2.3.2). [Indirect or “proxy” measurements such as ice-cores and tree-rings, provide inferences of pre-instrumental weather but with considerable uncertainty, IPCC AR6 2.3.1.1.1].

Finally, climate conditions may be examined through global maps of climate metrics, called Reanalyses, that are produced by major weather services who utilize a modeling framework to synthesize observations (including all those mentioned above) into a depiction of the global weather, generally every 6 hours. The most confident depictions begin in late 1978 when satellites started providing significant global information, though there are still uncertainties as input data tends to change with time in quality and distribution (IPCC AR6 1.5.2). A summary of these observational systems that measure climate conditions is provided in IPCC AR6 T1.2.1, 1.5.1 and 1.5.2.

From: Travis Fisher <travis.scott.fisher@gmail.com>
Sent: Sunday, April 20, 2025 11:37 AM
To: Roy Spencer
Cc: Ross McKittrick; Judith Curry; Steven Koonin; John Christy
Subject: Re: my mistake...

If it makes you feel any better, I'm on the same accelerated aging plan!

On Sun, Apr 20, 2025 at 11:21 AM Roy Spencer <roywspencer@hotmail.com> wrote:
All:

I erroneously told the group that the 2009 EF TSD had 1,800 pages and 1,800 references... this is because I have a binder with the EF TSD **PLUS** Chapter 12 of the IPCC AR6 report, "Climate Change Information for Regional Impact and for Risk Assessment", and my counting was from Chapter 12.

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Subject: Re: outline for a slimmed down report

I can put 10 together quickly, global greening, I have all the notes.

On Sat, Apr 19, 2025 at 7:12 PM Judith Curry <curry.judith@gmail.com> wrote:
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From: Judith Curry <curry.judith@gmail.com>

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Cc: Steven Koonin <steven.koonin@gmail.com>; Travis Fisher <travis.scott.fisher@gmail.com>; Roy Spencer <roywspencer@hotmail.com>; John Christy <climateman60@gmail.com>

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On Sat, Apr 19, 2025 at 3:18 PM Steven Koonin <steven.koonin@gmail.com> wrote:

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As I mentioned, I had the same thought of reorganizing the narrative as I read through the material this afternoon. Here's one way it might be done, pretty neatly divided into three sections

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Steve Koonin



Judith Curry, President
CFAN - Climate Forecast Applications Network
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curry.judith@cfanclimate.com | +1.404.803.2012
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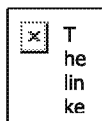
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From: Ross McKittrick [ross.mckittrick@gmail.com]
Sent: 4/19/2025 2:28:12 PM
To: Judith Curry [curry.judith@gmail.com]
CC: Travis Fisher [travis.scott.fisher@gmail.com]; John Christy [climateman60@gmail.com]; Roy Spencer [roywspencer@hotmail.com]; Steven Koonin [steven.koonin@gmail.com]
Subject: Re: I'll need help: 10 sections to go
Attachments: Fig_AR6_3.8_Apr18[JC].png

I also have some text on mortality impacts. Also I can add a bit to the vector-borne topic from my work on malaria a few years ago.

Sections 4.2 and 4.3 could easily be combined and build from what John already wrote.
Ross

On Sat, Apr 19, 2025 at 8:28 AM Judith Curry <curry.judith@gmail.com> wrote:
I can do 9 am (6 am PDT) for a call,

On Fri, Apr 18, 2025 at 7:57 PM Ross McKittrick <ross.mckittrick@gmail.com> wrote:
I'm thinking that a conference call or zoom meeting would be helpful so we can get caught up on the work done up to now and also the administrative side of things. Everything seems to be moving at a rapid pace. Could we schedule it for Monday morning at 9 ET?
Ross

On Fri, Apr 18, 2025 at 10:03 PM Travis Fisher <travis.scott.fisher@gmail.com> wrote:
Thanks so much, Judy!

Great questions. I don't think anyone has taken on the "air pollutant" issue. Please feel free to tackle it if you like!

Regarding the regulation in question, I've been told this summary of the science will be published as a technical support document relevant to a new proposed rule on tailpipe emissions standards for motor vehicles. I don't know whether that means all motor vehicles or just light- and medium-duty vehicles. It might be helpful to differentiate GHG emissions from the different classes to give the EPA flexibility in that regard.

The previous administration combined the rules for GHGs and criteria pollutants into a "multi-pollutant" rule, and I don't have any information on how this administration will package the different emissions standards. The exact charge for you all is to provide an update on the science relevant to the EPA's endangerment determination with respect to GHGs. As I understand the assignment, the scope is only GHGs, not criteria pollutants.

Keep the questions coming! I can run them up the chain if I don't know the answers, and I am happy to relay any questions you all have to the relevant folks at DOE or other agencies.

For your awareness, I was asked to share the table of contents with the EPA team this evening, which I did (the April 18 version), with the understanding that it is a one-way street (me informing them of your work so they know what's coming, not them sending feedback or micro-managing it). As I assured Steve in the early stages of this work, scientific integrity is paramount, and I will do everything in my power to preserve every word of the document as you all write it. In fact, the EPA team asked that the document be DOE-branded, meaning our true audience is the Secretary of Energy, and he emphasized to me that he wants nothing but

science. In other words, the only compromise you have to make in how this is written is among yourselves, not between you all and policymakers, lawyers, or economists.

Thanks again for lending your expertise to this effort, all of you.

Best,
Travis

On Fri, Apr 18, 2025 at 8:46 PM Judith Curry <curry.judith@gmail.com> wrote:

I have a lot of material already written that should be relevant. I have a draft of the sea level rise section completed, am sending this to my assistant to format, will upload monday.

Roy, let me know if there are sections you can't complete, i may have some text that is already written

On Fri, Apr 18, 2025 at 3:06 PM Travis Fisher <travis.scott.fisher@gmail.com> wrote:

Good afternoon,

I'm happy to report that I just talked with Judy, and she accepted the mission (in case you're wondering, the vetting issue was a mishap). This is great news because the Secretary wanted all of you to be able to contribute.

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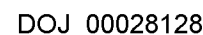
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A threshold question raised in Justice Scalia's dissent in *Mass v. EPA* (which can be found [here](#)) is whether CO₂ falls under the definition of an "air pollutant" under the Clean Air Act. The majority in *Mass v. EPA* found that *any* compound emitted into the ambient air fits the definition of "air pollutant," leading to a colorful footnote in the Scalia dissent ("It follows that everything airborne, from Frisbees to flatulence, qualifies as an 'air pollutant.' This reading of the statute defies common sense."). A scientific interpretation of this definition could be very helpful.

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As you all develop the draft, I encourage you to include as many citations to published materials as possible (links would work fine as placeholders). I have found this works better under a tight timeline than going back and looking for sources later. Please also feel free to task me with any research help you might need.

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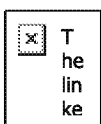
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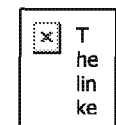
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Sent: Saturday, April 19, 2025 8:28 AM
To: Ross McKittrick
Cc: Travis Fisher; John Christy; Roy Spencer; Steven Koonin
Subject: Re: I'll need help: 10 sections to go

I can do 9 am (6 am PDT) for a call,

On Fri, Apr 18, 2025 at 7:57 PM Ross McKittrick <ross.mckittrick@gmail.com> wrote:

I'm thinking that a conference call or zoom meeting would be helpful so we can get caught up on the work done up to now and also the administrative side of things. Everything seems to be moving at a rapid pace. Could we schedule it for Monday morning at 9 ET?
Ross

On Fri, Apr 18, 2025 at 10:03 PM Travis Fisher <travis.scott.fisher@gmail.com> wrote:

Thanks so much, Judy!

Great questions. I don't think anyone has taken on the "air pollutant" issue. Please feel free to tackle it if you like!

Regarding the regulation in question, I've been told this summary of the science will be published as a technical support document relevant to a new proposed rule on tailpipe emissions standards for motor vehicles. I don't know whether that means all motor vehicles or just light- and medium-duty vehicles. It might be helpful to differentiate GHG emissions from the different classes to give the EPA flexibility in that regard.

The previous administration combined the rules for GHGs and criteria pollutants into a "multi-pollutant" rule, and I don't have any information on how this administration will package the different emissions standards. The exact charge for you all is to provide an update on the science relevant to the EPA's endangerment determination with respect to GHGs. As I understand the assignment, the scope is only GHGs, not criteria pollutants.

Keep the questions coming! I can run them up the chain if I don't know the answers, and I am happy to relay any questions you all have to the relevant folks at DOE or other agencies.

For your awareness, I was asked to share the table of contents with the EPA team this evening, which I did (the April 18 version), with the understanding that it is a one-way street (me informing them of your work so they know what's coming, not them sending feedback or micro-managing it). As I assured Steve in the early stages of this work, scientific integrity is paramount, and I will do everything in my power to preserve every word of the document as you all write it. In fact, the EPA team asked that the document be DOE-branded, meaning our true audience is the Secretary of Energy, and he emphasized to me that he wants nothing but science. In other words, the only compromise you have to make in how this is written is among yourselves, not between you all and policymakers, lawyers, or economists.

Thanks again for lending your expertise to this effort, all of you.

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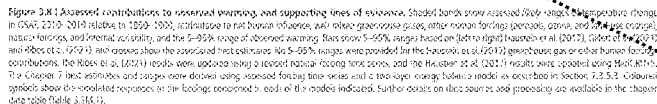
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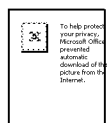
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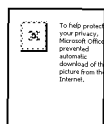
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To: Roy Spencer
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Subject: Re: I'll need help: 10 sections to go

I have text on mortality from heat and cold

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All:

Following are the sections I am least comfortable with writing. They have sections in the September 2024 draft TSD many of you have been privy to because either (1) I wrote them since no one else could be found in time to help, or (2) David Legates wrote them.

So, these are the ones that I'd appreciate help on:

- 2.3 Mortality risks from extreme heat and cold** (this was David Legates' work in the September 2024 draft TSD)
- 2.4 Changes in sea level rise** (Judy has done a lot on this, and a very condensed version of her work would be appropriate here).
- 3.5 Climate change and vector-borne diseases** (again, David Legates, but I could condense what he produced if no one else feels "expert" on this)
- 4.2 US vehicle emissions as a fraction of global CO2 emissions** (John, since you spent time on this, maybe you can provide something?)
- 4.3 The effect on the global climate system of variations in US tailpipe CO2 emissions** (should this be combined with section 4.2?)

If I'm still considered the best source for any of these, I will use the aforementioned document to provide input.

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Judy

Sounds like you're jumping in with both feet. I'm not aware of our role on the legal aspect of "air pollutant", but I think we'd like to see what you have. Travis is our guide, but we're really all throwing what we have together now to build a good draft by the end of the month. Steve will be back from India tomorrow and Ross is keeping track of the Master document.

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Glad you're aboard.

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To help protect
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Sent: Saturday, April 19, 2025 6:08 AM
To: John Christy; Judith Curry
Cc: Travis Fisher; Ross McKittrick; Steven Koonin
Subject: Re: I'll need help: 10 sections to go

All:

Following are the sections I am least comfortable with writing. They have sections in the September 2024 draft TSD many of you have been privy to because either (1) I wrote them since no one else could be found in time to help, or (2) David Legates wrote them.

So, these are the ones that I'd appreciate help on:

- 2.3 Mortality risks from extreme heat and cold** (this was David Legates' work in the September 2024 draft TSD)
- 2.4 Changes in sea level rise** (Judy has done a lot on this, and a very condensed version of her work would be appropriate here).
- 3.5 Climate change and vector-borne diseases** (again, David Legates, but I could condense what he produced if no one else feels "expert" on this)
- 4.2 US vehicle emissions as a fraction of global CO2 emissions** (John, since you spent time on this, maybe you can provide something?)
- 4.3 The effect on the global climate system of variations in US tailpipe CO2 emissions** (should this be combined with section 4.2?)

If I'm still considered the best source for any of these, I will use the aforementioned document to provide input.

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Judy

Sounds like you're jumping in with both feet. I'm not aware of our role on the legal aspect of "air pollutant", but I think we'd like to see what you have. Travis is our guide, but we're really all throwing what we have together now to build a good draft by the end of the month. Steve will be back from India tomorrow and Ross is keeping track of the Master document.

I'm still trying to figure out Dropbox, so for now I'm sending pieces to Ross.

Glad you're aboard.

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Thanks so much, Judy!

Great questions. I don't think anyone has taken on the "air pollutant" issue. Please feel free to tackle it if you like!

Regarding the regulation in question, I've been told this summary of the science will be published as a technical support document relevant to a new proposed rule on tailpipe emissions standards for motor vehicles. I don't know whether that means all motor vehicles or just light- and medium-duty vehicles. It might be helpful to differentiate GHG emissions from the different classes to give the EPA flexibility in that regard.

The previous administration combined the rules for GHGs and criteria pollutants into a "multi-pollutant" rule, and I don't have any information on how this administration will package the different emissions standards. The exact charge for you all is to provide an update on the science relevant to the EPA's endangerment determination with respect to GHGs. As I understand the assignment, the scope is only GHGs, not criteria pollutants.

Keep the questions coming! I can run them up the chain if I don't know the answers, and I am happy to relay any questions you all have to the relevant folks at DOE or other agencies.

For your awareness, I was asked to share the table of contents with the EPA team this evening, which I did (the April 18 version), with the understanding that it is a one-way street (me informing them of your work so they know what's coming, not them sending feedback or micro-managing it). As I assured Steve in the early stages of this work, scientific integrity is paramount, and I will do everything in my power to preserve every word of the document as you all write it. In fact, the EPA team asked that the document be DOE-branded, meaning our true audience is the Secretary of Energy, and he emphasized to me that he wants nothing but science. In other words, the only compromise you have to make in how this is written is among yourselves, not between you all and policymakers, lawyers, or economists.

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I've uploaded a new version of Section 2.2 to your folder. It includes the earlier material quoting all the relevant IPCC and NCA17 stuff and adds some external source information I found. Still needs a brief summary. Others may have more to add.

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Cc: Travis Fisher <travis.scott.fisher@gmail.com>, Steven Koonin <steven.koonin@gmail.com>, John Christy <climateman60@gmail.com>

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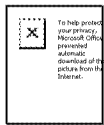
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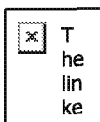
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curry.judith@cfanclimate.com |
+1.404.803.2012
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To: Judith Curry
Subject: Re: I'll need help: 10 sections to go
Attachments: Fig_AR6_3.8_Apr18[JC].png

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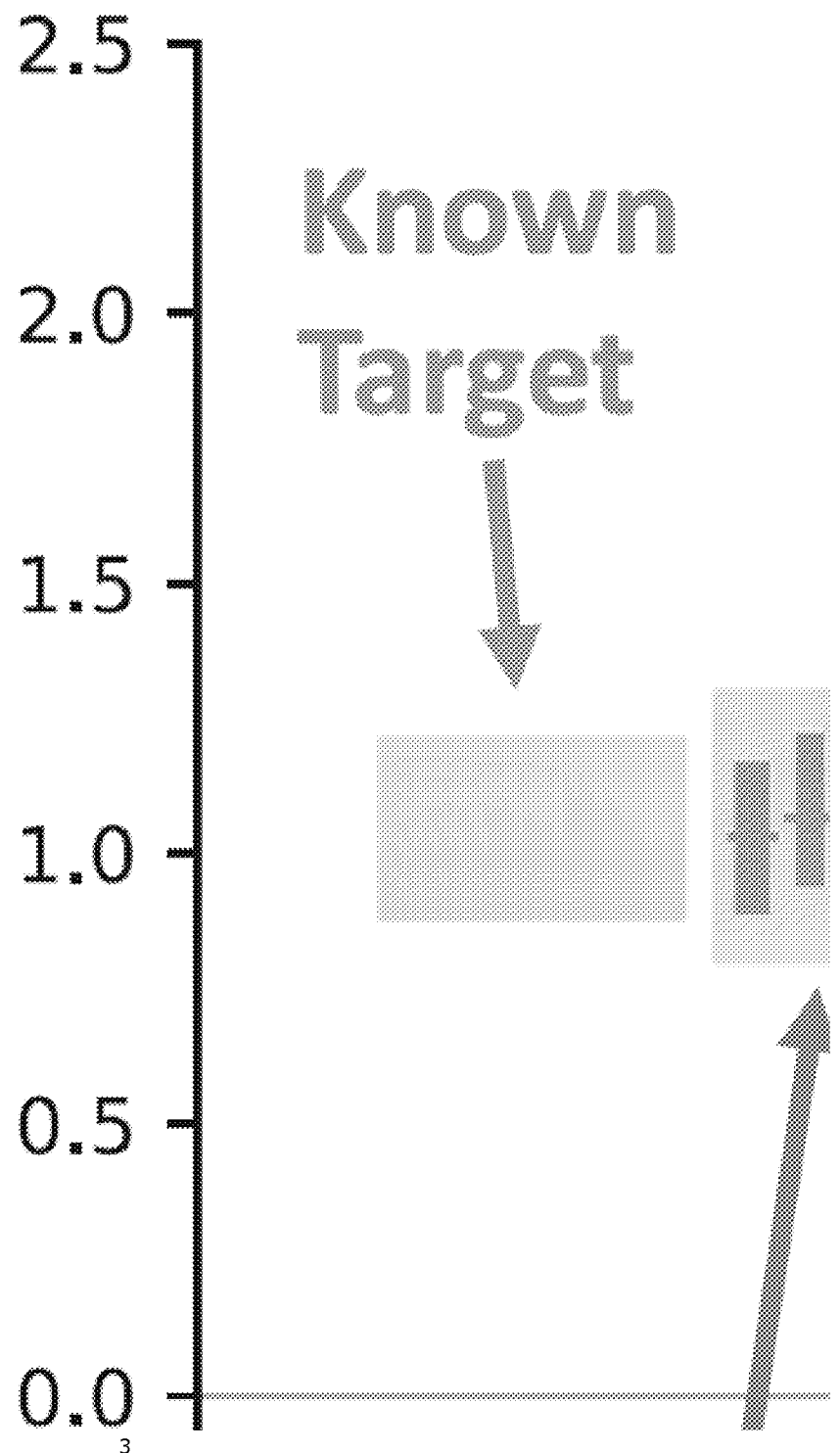
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Chapter 3

GSAT, 2010-2019 vs 1850-1900 (°C)



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Sent: Friday, April 18, 2025 6:34 AM

To: Ross McKittrick <ross.mckittrick@gmail.com>; Travis Fisher <travis.scott.fisher@gmail.com>
Cc: Steven Koonin <steven.koonin@gmail.com>; John Christy <climateman60@gmail.com>
Subject: Section 1.4.3 attached

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I think we should combine sections 1.4.3 and 1.4.4 (attached) which I now call "The carbon cycle, emissions scenarios, and global greening".

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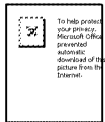
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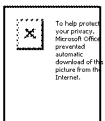
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<DE.memo.outline.Apr.11.[RM].docx>



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curry.judith@cfanclimate.com | +1.404.803.2012
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Sent: 4/18/2025 11:55:52 PM
To: Ross McKittrick [ross.mckittrick@gmail.com]
Subject: Re: I'll need help: 10 sections to go

Are we sticking with medium emissions scenario (4.5), or are we also including 8.5?

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Cheers
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Let's make sure to include Judy in all of our correspondence from now on. The documents should be available here: https://www.dropbox.com/scl/fo/wahx6lpwzu33m5vyri8x/ANTU1qAQJ-zXCFzP_gsJcOs?rlkey=l1z3qj9v46e1t5f4ywwxq7p8c&e=1&dl=0. Please let us know if you don't have access.

Best,
Travis

On Fri, Apr 18, 2025 at 4:59 PM Ross McKittrick <ross.mckitrick@gmail.com> wrote:
Thanks John. The quote from Mauritsen and Roeckner is a great addition.
I find the figure hard to follow, whereas the quote makes the point very clearly, in their own words.

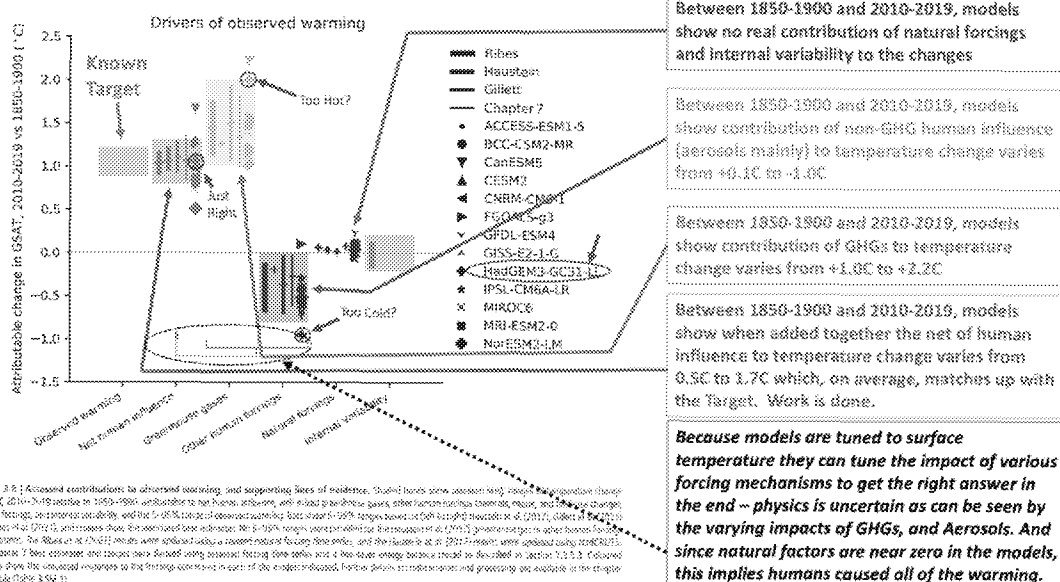
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Ross

I've never been successful with dropbox and my record is still intact.

Attached is 1.6.2 to which I added a paragraph.

Also attached is a chart I annotated from AR6. I think this story demonstrates modelers are just playing with tuning parameters. Is there some way to use this information here (not necessarily in this format)?

John C.



On Fri, Apr 18, 2025 at 3:32 PM Ross McKittrick <ross.mckittrick@gmail.com> wrote:

I've uploaded a new version of Section 2.2 to your folder. It includes the earlier material quoting all the relevant IPCC and NCA17 stuff and adds some external source information I found. Still needs a brief summary. Others may have more to add.

On Fri, Apr 18, 2025 at 3:05 PM Roy Spencer <roywspencer@hotmail.com> wrote:

Ross:

Let me look early in the morning to see which ones I feel like I can knock out the fastest. Our "guidance" has been to start from "scratch", while relying on preexisting materials where it helps. I think I know why we've been told this, but it's not my place to say.

- Roy

Sent from my Verizon, Samsung Galaxy smartphone

----- Original message -----

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Date: 4/18/25 10:49 AM (GMT-06:00)

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Cc: Travis Fisher <travis.scott.fisher@gmail.com>, Steven Koonin <steven.koonin@gmail.com>, John Christy <climateman60@gmail.com>

Subject: Re: I'll need help: 10 sections to go

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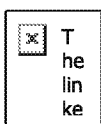
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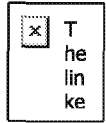
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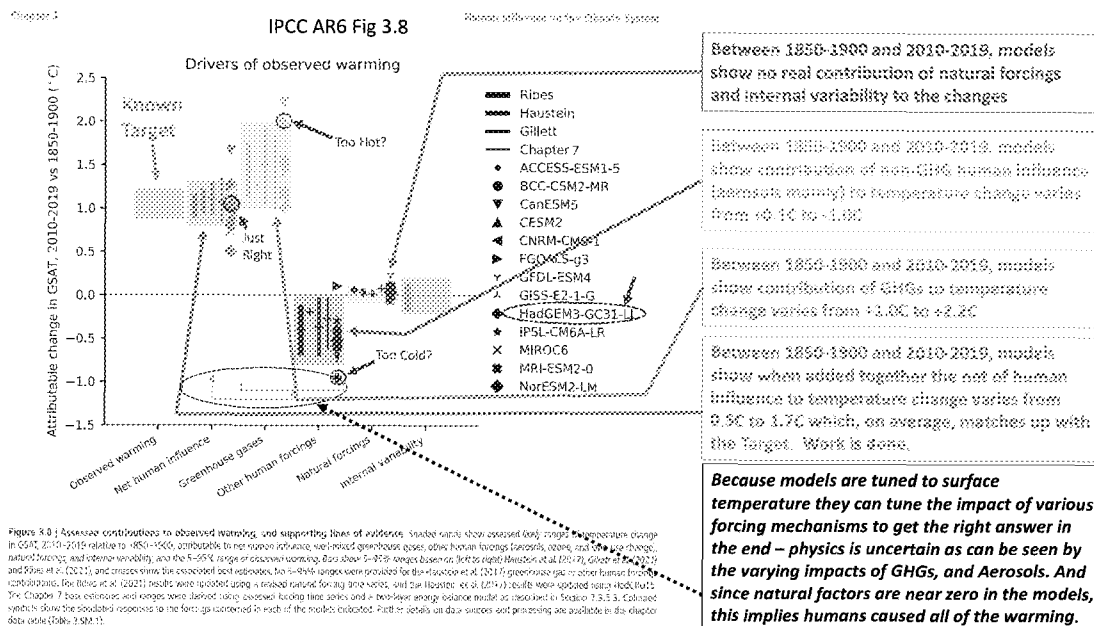
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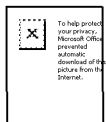
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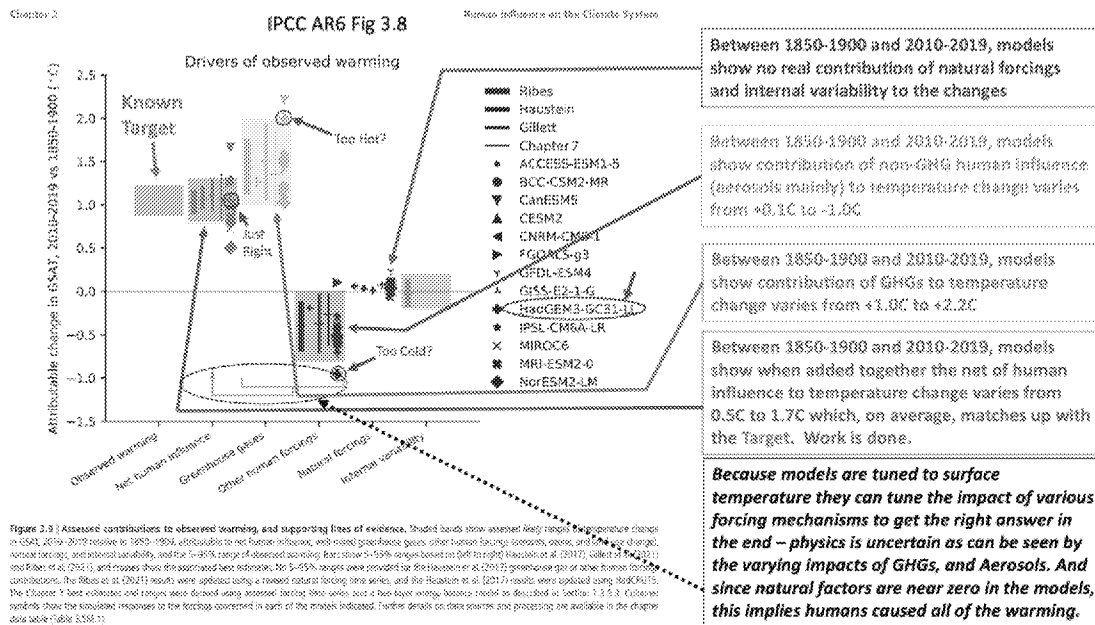
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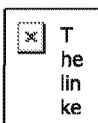
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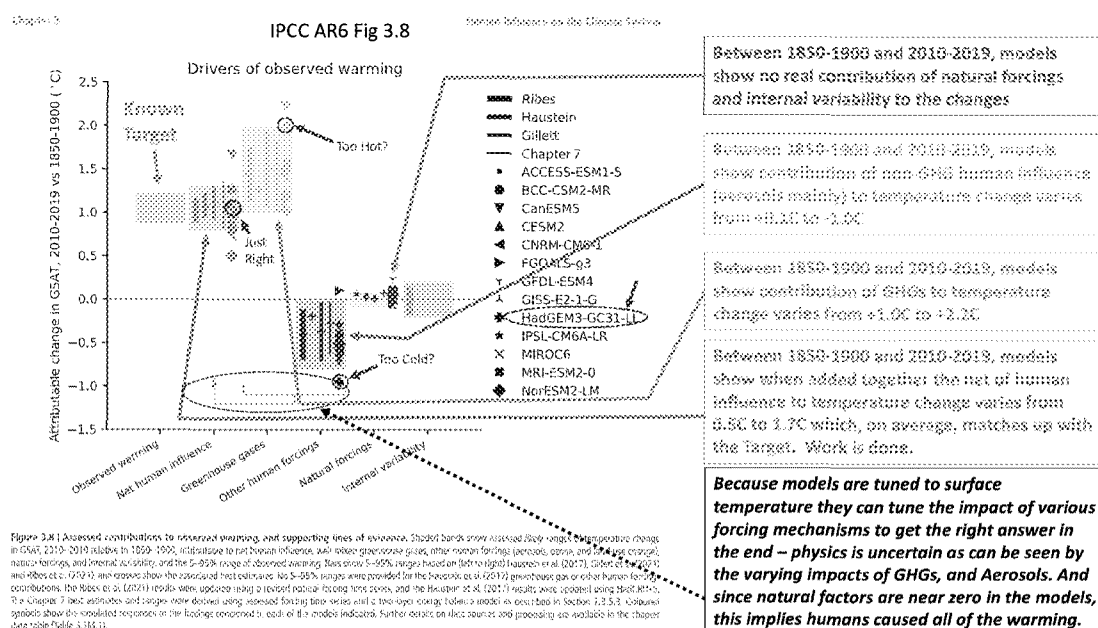
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- Roy

Sent from my Verizon, Samsung Galaxy smartphone

----- Original message -----

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Date: 4/18/25 10:49 AM (GMT-06:00)

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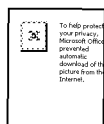
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<DE.memo.outline.Apr.11.[RM].docx>



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CFAN - Climate Forecast Applications Network
Reno, NV USA
curry.judith@cfanclimate.com | +1.404.803.2012
<http://www.cfanclimate.net>

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Subject: Re: I'll need help: 10 sections to go
Attachments: Fig_AR6_3.8_Apr18[JC].png

That's great news. Your assistance will be greatly appreciated Judy. I added a folder for you in the Dropbox. I just uploaded to the Dropbox the latest Table of Contents with the changes I noted this afternoon plus a couple of other changes. As before bold indicates a draft is done and underlining indicates a section title but no text is needed. Coding to indicate responsibility now gets more complicated because JC has two meanings. So I marked a couple JCurry which indicate my suggestions, namely Judy would you consider writing up something on Forecasting systems for managing extreme weather risks, and Changes in sea level. In both cases the overarching focus is evaluating endangerment to the US public of rising GHG levels.

At this point to minimize multiple conflicting drafts each section is being written in its own separate document by whoever is designated lead on it, so you can just open new docs for both these sections, assuming you're amenable to the assignment. Once there is something like a complete draft everyone will get to weigh in on every section and also on the conclusions.

Cheers

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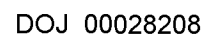
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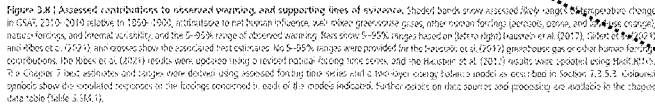
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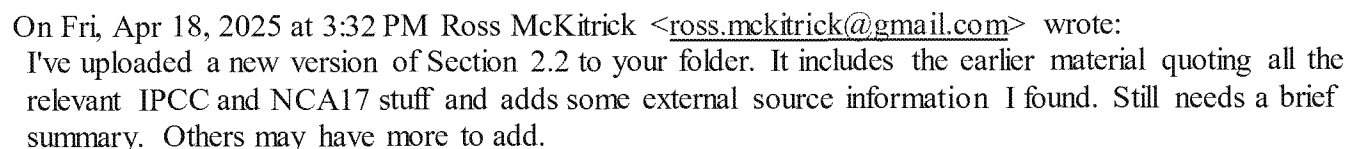
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DOJ 00028219

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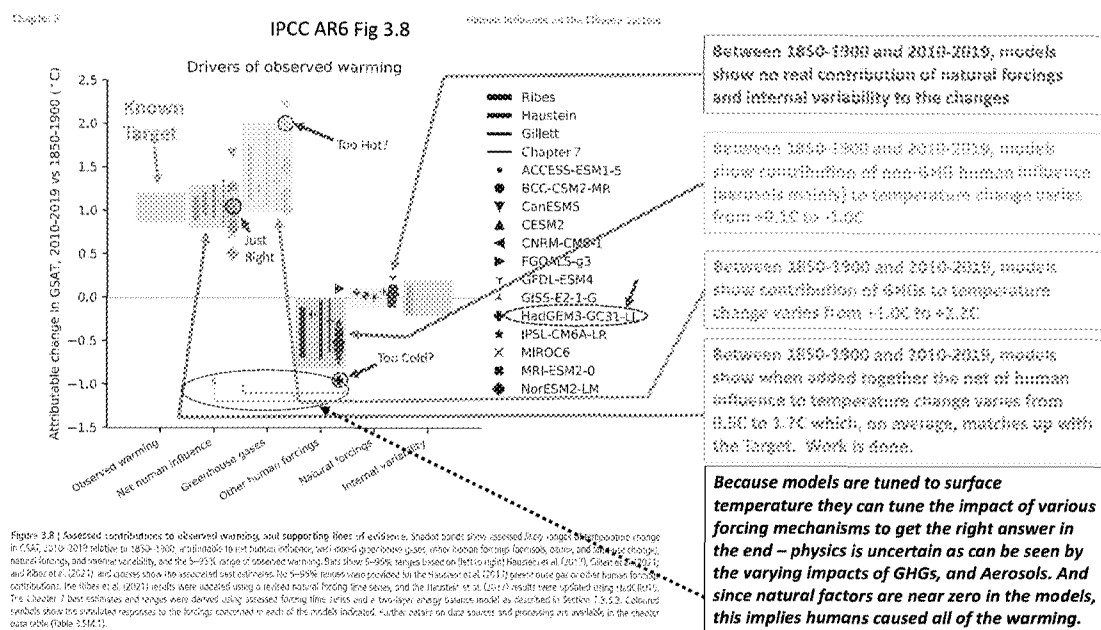
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Empirical methods [RM]

Equilibrium Climate Sensitivity (ECS) is defined as the expected amount of warming averaged over the Earth's surface in response to a doubling of CO₂, after all climate systems have had time to adjust. Some systems, like temperatures in the troposphere, adjust very rapidly. Others may take decades or even centuries, such as the deep ocean and the cryosphere. A related metric which is sometimes more helpful on shorter time scales is the Transient Climate Response (TCR) defined as the amount of warming after 70 years in which atmospheric CO₂ goes up by one percent annually.

In large-scale General Circulation Models (aka climate models) ECS is not imposed as a direct parameter, instead it emerges from the behaviour of the underlying components of the model. These, however, are under the control of the modeler, so ultimately a model's ECS can be said to be built into it. Direct warming from CO₂ doubling is only about 1°C; the rest (to the extent more happens) arises due to climate feedbacks which are inherently more difficult to predict and model.

In 1979 the Charney (1979) Report for the US National Academy of Sciences proposed that the most likely value for ECS was 3.0°C plus or minus 1.5°C. Hence the best estimate was a likely tripling of the CO₂ effect through feedbacks. With only minor variations this range was adopted and reaffirmed by the IPCC until the most recent AR6. The range has been obtained primarily by examining the behaviour of climate models, but since key components of models are under the control of modelers this is not determinative of the actual climate's sensitivity. For example, Mauritsen and Roeckner (2020) confess regarding their Max Planck Institute model, "We have documented how we tuned the MPI-ESM1.2 global climate model to match the instrumental record of warming; an endeavor which has clearly been successful. Due to the historical order of events, the choice was to do this practically by *targeting an ECS of about 3 K using cloud feedbacks*, [emphasis added] as opposed to tuning the aerosol forcing." In other words, without appealing to fundamental physics the modelers chose an ECS of 3 K then tuned the cloud feedbacks to match their intended result.

A significant amount of effort has gone into estimating ECS empirically. There are several challenges to this work.

- First, it requires good data but observations of some key climatic systems, especially the oceans, are available in only very limited amounts.
- Second, identifying the effect of CO₂ requires simultaneously identifying the effect of aerosols. Climate models exhibit warming in response to GHGs but cooling in response to aerosols (Schwartz et al. 2007). Observed 20th century warming can be shown to be consistent either with low ECS and low aerosol cooling or high ECS and high aerosol cooling. Since fossil fuel use adds both GHGs and aerosols to the atmosphere, both effects need to be estimated to isolate the warming effect of CO₂. Over time the IPCC's estimate of the cooling effect of aerosols has declined (Lewis 2022).
- Third, the simple empirical model typically used for the estimation, called an Energy Balance Model, requires estimating a feedback parameter which appears in the denominator of the equation for ECS. A small amount of uncertainty about the number in the denominator of a fraction can lead to very large uncertainties in the magnitude of the fraction itself. Roe and Baker (2007) pointed out that uncertainties in climate feedbacks are "highly amplified" in the resulting ECS.

Since 2012 many studies have appeared in the literature tackling these various uncertainties. A recurring theme is that ECS estimates based on historical data turn out to be smaller than ECS estimates inferred from climate models (Sherwood and Forest 2024). An early estimate (Stern and Kaufmann 2000) was 1.6°C, though this predated development of the Energy Balance Model method. Figure 1.6.1 shows the point or best estimates from 17 subsequent studies all appearing in the peer-reviewed literature after the TSD. The Charney range is shown for contrast. The average ECS estimate in the post-2012 sample is 1.8°C. The highest estimate, from Sherwood et al. 2020, is shown in red: it is the one that was used by the IPCC for the AR6 (Forster et al. 2021). The one adjacent to it, Lewis (2022), shows the result of, among other things, using the same method but applying more updated aerosol forcing data in the AR6 as well as some other recent updates to the source data. These updates dropped the ECS best estimate back down closer to the usual empirical range. The IPCC, following Sherwood et al. (2020) had estimated only a 5 percent probability that ECS was below 2.3°C was only 5 percent, whereas Lewis (2022) estimated it was over 50 percent.

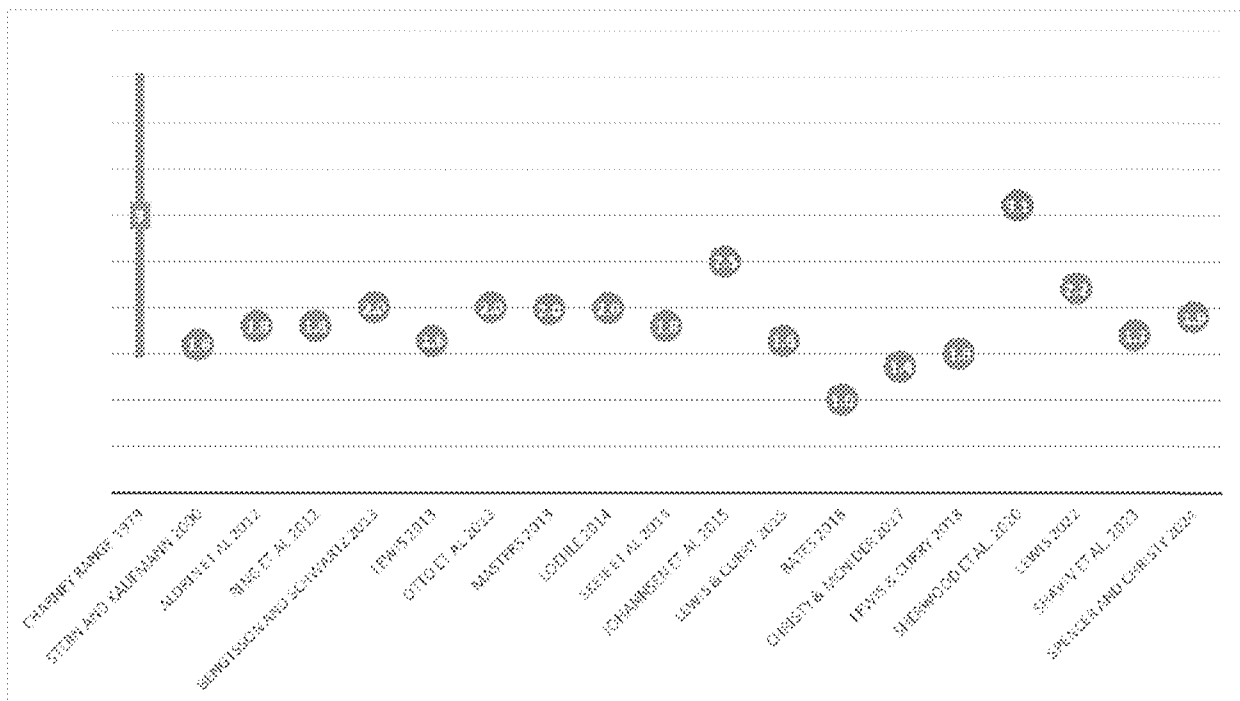


Figure 1.6.1: Empirical best estimates of ECS

A recent argument, one which the IPCC emphasized, that empirical ECS estimates might understate the future warming response to GHGs is based on a so-called “pattern effect” (Forster et al 2021). The tropical Pacific is believed to be highly influential on the overall efficiency with which the Earth’s climate radiates heat to space, but heat in some parts is more efficiently removed than from others. If in a warming climate there is a weakening of the west-to-east temperature gradient in the tropical Pacific the result would be a concentration of warming in a region where heat is less efficiently removed, raising the ECS of the Earth’s climate system. Most climate models simulate that rising GHGs will weaken the east-west temperature gradient, which led the IPCC in the AR6 to conclude that empirical ECS estimates understated what would be the *future* observed ECS value.

However Seager et al. (2019) pointed out that, contrary to models, the east-west temperature gradient has been strengthening rather than weakening over time. They further argued that the mechanism predicting otherwise in climate models was based on a faulty characterization of oceanic dynamics and there is no reason to expect the gradient to weaken. A similar argument was recently made by Lee et al. (2024), who concluded that “the trajectory of the observed trend reflects the response to increasing GHG loading in the atmosphere”, in other words GHG warming should lead to a future strengthening rather than a weakening of the temperature gradient. This implies, if anything, that future ECS in a warming climate will be lower than at present.

In summary, while the ECS range in climate models is very wide, historically climate models have embedded processes and assumptions that about secondary feedbacks that approximately triple the warming from CO₂. Empirical estimates since the TSD however imply the climate is much less sensitive to CO₂ than this, with the estimates centered at or below 2°C. As discussed in Section 1.4.2 this is supported by studies which show climate models on average estimate too much warming at the surface and in the troposphere compared to observations over the past 50 years, and low-ECS models do better than high-ECS ones. Also this aligns with evidence from consistent fingerprinting (Section 1.5.1) that model responses to GHGs need to be scaled down quite a bit to align with observed trends. As will be discussed in Section 3.6, ECS values in the range of 2.0°C imply very low Social Cost of Carbon values.

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From: Ross McKittrick [ross.mckittrick@gmail.com]
Sent: 4/18/2025 8:32:32 PM
To: Roy Spencer [roywspencer@hotmail.com]
CC: Travis Fisher [travis.scott.fisher@gmail.com]; Steven Koonin [steven.koonin@gmail.com]; John Christy [climateman60@gmail.com]
Subject: Re: I'll need help: 10 sections to go

I've uploaded a new version of Section 2.2 to your folder. It includes the earlier material quoting all the relevant IPCC and NCA17 stuff and adds some external source information I found. Still needs a brief summary. Others may have more to add.

On Fri, Apr 18, 2025 at 3:05 PM Roy Spencer <roywspencer@hotmail.com> wrote:

Ross:

Let me look early in the morning to see which ones I feel like I can knock out the fastest. Our "guidance" has been to start from "scratch", while relying on preexisting materials where it helps. I think I know why we've been told this, but it's not my place to say.

- Roy

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Cc: Travis Fisher <travis.scott.fisher@gmail.com>, Steven Koonin <steven.koonin@gmail.com>, John Christy <climateman60@gmail.com>

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I don't see how I'm going to do the 10 more sections assigned to me (1.6.1 onward) in the time remaining. Feel free to jump in.

-Roy

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Subject: Section 1.4.3 attached

Ross:

I think we should combine sections 1.4.3 and 1.4.4 (attached) which I now call "The carbon cycle, emissions scenarios, and global greening".

I found that all of these need to be discussed together. Feel free to reword the section title.

-Roy

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Cc: Steven Koonin <steven.koonin@gmail.com>; John Christy <climateman60@gmail.com>
Subject: Section 1.4.2 Can climate models reproduce the recent past?

Attached. This is the minimum I think needs to be in this section. Of course, more could be added, but I think we need to stick to our strongest arguments, given the limited time available.

-Roy

From: Roy Spencer <roywspencer@hotmail.com>
Sent: Wednesday, April 16, 2025 7:16 AM
To: Ross McKittrick <ross.mckittrick@gmail.com>; Travis Fisher <travis.scott.fisher@gmail.com>
Cc: Steven Koonin <steven.koonin@gmail.com>; John Christy <climateman60@gmail.com>
Subject: Some Spencer inputs

I took it upon myself to write a preamble in **Section 1.3 Drivers of climate change** (attached), which seemed necessary to introduce some basic concepts.

Also attached are my initial submissions for **1.3.2** and **1.3.3**.

NO references added yet.

One of the things I believe we need to watch out for is *neglecting to come to conclusions along the way*... There is a tendency to get mired in the technical details without getting around to saying what each section might mean in eventual policy decisions related to the Endangerment Finding. In my experience, it is not possible to dumb-down this stuff too much. I suggest some sort of "Summary Boxes" with 1-2 simplified statements highlighting a main conclusion of each section that would have policy relevance.

-Roy

From: Ross McKittrick <ross.mckittrick@gmail.com>
Sent: Monday, April 14, 2025 1:37 PM
To: Travis Fisher <travis.scott.fisher@gmail.com>

Cc: Steven Koonin <steven.koonin@gmail.com>; John Christy <climateman60@gmail.com>;
roywspencer@hotmail.com <roywspencer@hotmail.com>

Subject: Re: Kickoff

Hi Travis

We developed the outline a bit further and assigned sections out yesterday. We'll keep you cc'd going forward.

Here is a Dropbox link that contains the current outline (also attached) which indicates who is working on each section

https://www.dropbox.com/sc/fo/wahx6lpwzu33m5vyrr8x/ANTU1qAQJ-zXCFzP_gsjcOs?rlkey=llz3qj9v46e1t5f4ywwxq7p8c&dl=0

The link should give you all editing privileges.

I put folders in there for each of us. If the use of that Dropbox (which is on my own account) is acceptable for this project then we can share our work using it. Otherwise once we have an official Dropbox created we can transfer the material over to it.

Do you think it would be helpful to have a section specifically addressing the question of whether CO2 is a pollutant like CO, NOx, SOx, PM, etc.? If you want to add topics or suggest changes please do, the earlier the better as we begin filling out the contents.

Cheers,

Ross

On Mon, Apr 14, 2025 at 2:12 PM Travis Fisher <travis.scott.fisher@gmail.com> wrote:

This is an excellent start! Can we move forward by iterating with this document for now? Please feel free to add whatever material you like, and I can collate if there are any simultaneous changes. I will leave the substance to you all because I view my role as a facilitator rather than a contributor, but please let me know how I can be most helpful.

Steve is correct that this document should be clear and understandable for non-experts. My understanding is that it should also be sufficiently technical and comprehensive to inform policymakers on all relevant aspects of the science.

One area I can help with might be targeting your work for the very brief window we have open at the moment. I am including a few lines verbatim below from key documents to highlight the areas of inquiry that are most relevant to the policymaking process. Of course, you all should make your own judgments about what to include versus what to leave out.

Here is a key section of the Clean Air Act, 202(a)(1): "The Administrator shall by regulation prescribe (and from time to time revise) in accordance with the provisions of this section, standards applicable to the emission of any air pollutant from any class or classes of new motor vehicles or new motor vehicle engines, which in his judgment cause, or contribute to, air pollution which may reasonably be anticipated to endanger public health or welfare. Such standards shall be applicable to such vehicles and engines for their useful life (as determined under subsection (d), relating to useful life of vehicles for purposes of certification), whether such vehicles and engines are designed as complete systems or incorporate devices to prevent or control such pollution."

Section 202 can be found [here](#).

Here is another key section of the Clean Air Act, section 302(g): "The term 'air pollutant' means any air pollution agent or combination of such agents, including any physical, chemical, biological, radioactive (including source material, special nuclear material, and byproduct material) substance or matter which is emitted into or otherwise enters the ambient air. Such term includes any precursors to the formation of any air pollutant, to the extent the Administrator has identified such precursor or precursors for the particular purpose for which the term 'air pollutant' is used."

A threshold question raised in Justice Scalia's dissent in *Mass v. EPA* (which can be found [here](#)) is whether CO2 falls under the definition of an "air pollutant" under the Clean Air Act. The majority in *Mass v. EPA* found that *any* compound emitted into the ambient air fits the definition of "air pollutant," leading to a colorful footnote in the Scalia dissent ("It follows that everything airborne, from Frisbees to flatulence, qualifies as an 'air pollutant.' This reading of the statute defies common sense."). A scientific interpretation of this definition could be very helpful.

The next section in the statute is 302(h), which defines effects on welfare: "All language referring to effects on welfare includes, but is not limited to, effects on soils, water, crops, vegetation, manmade materials, animals, wildlife, weather, visibility, and climate, damage to and deterioration of property, and hazards to transportation, as well as effects on economic values and on personal comfort and well-being, whether caused by transformation, conversion, or combination with other air pollutants." Positive impacts, including fertilization effects and beneficial warming, seem to be within scope here.

Section 302 can be found [here](#).

As you all develop the draft, I encourage you to include as many citations to published materials as possible (links would work fine as placeholders). I have found this works better under a tight timeline than going back and looking for sources later. Please also feel free to task me with any research help you might need.

Best,
Travis

On Fri, Apr 11, 2025 at 8:10 PM Steven Koonin <steven.koonin@gmail.com> wrote:

I assume we're writing for non-experts. If so, some educating beyond the root questions is in order (it always helps if people feelsmarter after reading).

So I've taken Ross' material, added some broader context, and cast it into the forcing/response/impact syllogism that most non-experts seem to get. The result is attached.

I think we can deal with the differences relative to 2009 in an appendix.

SEK

From: John Christy <climateman60@gmail.com>

Sent: Friday, April 11, 2025 6:34 PM

To: Ross McKittrick <ross.mckittrick@gmail.com>

Cc: Travis Fisher <travis.scott.fisher@gmail.com>; steven.koonin@gmail.com; roywspencer@hotmail.com

Subject: Re: Kickoff

Excellent list Ross. Wildfires are a significant topic to be addressed.

John C.

Sent from my iPhone

On Apr 11, 2025, at 4:05 PM, Ross McKittrick <ross.mckittrick@gmail.com> wrote:

The attached represents my summary of the most questions needing to be answered, which I think this group is capable of answering in the next couple of weeks. Probably lots of material already in hand.

On Fri, Apr 11, 2025 at 4:24 PM Travis Fisher <travis.scott.fisher@gmail.com> wrote:

Gentlemen,

I can't thank you enough for taking this on under such a tight timeline. Let's use this thread to exchange information, links, etc., and as we move forward, I'll see about a document-sharing platform and a shared document to work on simultaneously.

Best,
Travis

<DE.memo.outline.Apr.11.[RM].docx>

From: Roy Spencer <roywspencer@hotmail.com>
Sent: Friday, April 18, 2025 3:06 PM
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Cc: Travis Fisher; Steven Koonin; John Christy
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Sent: Friday, April 18, 2025 12:33 PM
To: Roy Spencer
Cc: Ross McKittrick; Travis Fisher; Steven Koonin
Subject: Re: I'll need help: 10 sections to go

Roy

After class, I'll try to finish my last section and then take a look at what you have left.

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Sorry Roy, I didn't mean to swamp you, I figured those were sections you already had in the can from previous work. Looking through my own folders I have some material I forgot I had written which I can repurpose. Can you send a list of the sections you are able to do, and the ones you would like to hand off for the time being?

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This is an excellent start! Can we move forward by iterating with this document for now? Please feel free to add whatever material you like, and I can collate if there are any simultaneous changes. I will leave the substance to you all because I view my role as a facilitator rather than a contributor, but please let me know how I can be most helpful.

Steve is correct that this document should be clear and understandable for non-experts. My understanding is that it should also be sufficiently technical and comprehensive to inform policymakers on all relevant aspects of the science.

One area I can help with might be targeting your work for the very brief window we have open at the moment. I am including a few lines verbatim below from key documents to highlight the areas of inquiry that are most relevant to the policymaking process. Of course, you all should make your own judgments about what to include versus what to leave out.

Here is a key section of the Clean Air Act, 202(a)(1): "The Administrator shall by regulation prescribe (and from time to time revise) in accordance with the provisions of this section, standards applicable to the emission of any air pollutant from any class or classes of new motor vehicles or new motor vehicle engines, which in his judgment cause, or contribute to, air pollution which may reasonably be anticipated to endanger public health or welfare. Such standards shall be applicable to such vehicles and engines for their useful life (as determined under subsection (d), relating to useful life of vehicles for purposes of certification), whether such vehicles and engines are designed as complete systems or incorporate devices to prevent or control such pollution."

Section 202 can be found [here](#).

Here is another key section of the Clean Air Act, section 302(g): "The term 'air pollutant' means any air pollution agent or combination of such agents, including any physical, chemical, biological, radioactive (including source material, special nuclear material, and byproduct material) substance or matter which is emitted into or otherwise enters the ambient air. Such term includes any precursors to the formation of any air pollutant, to the extent the Administrator has identified such precursor or precursors for the particular purpose for which the term 'air pollutant' is used."

A threshold question raised in Justice Scalia's dissent in *Mass v. EPA* (which can be found [here](#)) is whether CO2 falls under the definition of an "air pollutant" under the Clean Air Act. The majority in *Mass v. EPA* found that *any* compound emitted into the ambient air fits the definition of "air pollutant," leading to a colorful footnote in the Scalia dissent ("It follows that everything airborne, from Frisbees to flatulence, qualifies as an 'air pollutant.' This reading of the statute defies common sense."). A scientific interpretation of this definition could be very helpful.

The next section in the statute is 302(h), which defines effects on welfare: "All language referring to effects on welfare includes, but is not limited to, effects on soils, water, crops, vegetation, manmade materials, animals, wildlife, weather, visibility, and climate, damage to and deterioration of property, and hazards to transportation, as well as effects on economic values and on personal comfort and well-being, whether caused

by transformation, conversion, or combination with other air pollutants." Positive impacts, including fertilization effects and beneficial warming, seem to be within scope here.

Section 302 can be found [here](#).

As you all develop the draft, I encourage you to include as many citations to published materials as possible (links would work fine as placeholders). I have found this works better under a tight timeline than going back and looking for sources later. Please also feel free to task me with any research help you might need.

Best,
Travis

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I assume we're writing for non-experts. If so, some educating beyond the root questions is in order (it always helps if people feel smarter after reading).

So I've taken Ross' material, added some broader context, and cast it into the forcing/response/impact syllogism that most non-experts seem to get. The result is attached.

I think we can deal with the differences relative to 2009 in an appendix.

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From: John Christy <climateman60@gmail.com>

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To: Ross McKittrick <ross.mckitrick@gmail.com>

Cc: Travis Fisher <travis.scott.fisher@gmail.com>; steven.koonin@gmail.com; roywspencer@hotmail.com

Subject: Re: Kickoff

Excellent list Ross. Wildfires are a significant topic to be addressed.

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From: Roy Spencer <roywspencer@hotmail.com>
Sent: Friday, April 18, 2025 7:40 AM
To: Ross McKittrick; Travis Fisher
Cc: Steven Koonin; John Christy
Subject: I'll need help: 10 sections to go

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Subject: Section 1.4.3 attached

Ross:

I think we should combine sections 1.4.3 and 1.4.4 (attached) which I now call "The carbon cycle, emissions scenarios, and global greening".

I found that all of these need to be discussed together. Feel free to reword the section title.

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Subject: Section 1.4.2 Can climate models reproduce the recent past?

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<DE.memo.outline.Apr.11.[RM].docx>

From: Judith Curry [curry.judith@gmail.com]
Sent: 4/19/2025 3:14:24 PM
To: Ross McKittrick [ross.mckittrick@gmail.com]
CC: Roy Spencer [roywspencer@hotmail.com]; Travis Fisher [travis.scott.fisher@gmail.com]; John Christy [climatemanager60@gmail.com]; Steven Koonin [steven.koonin@gmail.com]
Subject: Re: Our authorship vs. that of the EPA's 2009 EF TSD

The issues that Ross raises are important, and I think that the deadline needs to be pushed back for a variety of reasons.

Apart from the issues raised by Ross in terms of a lack of formal designation of responsibility and statement of task (an official letter or something) and arrangement for compensation (I understand why this one would take awhile), I don't want my name associated with a document that hasn't been carefully vetted and agreed upon by all of the authors.

I will continue to work on this over the next two weeks, but I agree that the status of any document we produce should be regarded as draft work product and not distributed outside of the DOE leadership, until these issues are resolved

On Sat, Apr 19, 2025 at 7:23 AM Ross McKittrick <ross.mckittrick@gmail.com> wrote:

Travis, At this point I do not authorize you to share any work product I have contributed with any other group inside or outside the US government. At this point I am sharing notes with some colleagues on some topics of mutual interest in my private capacity as a non-US citizen. I am not a DoE employee or contractor and this is not a DoE work product.

I realize that people on your end have a use in mind for this material although so far no one has done us the courtesy of offering a clear explanation of exactly what we are being asked to do. I can't be expected to attach any more importance to contributing to the project than you guys attach to me being involved in it. So far, other than the original phone call recruiting me no one on your end has indicated you perceive any tangible value to having me involved. Providing a TSD to support a reassessment of the EF is very demanding and puts authors on the hook for a long time into the future to deal with what will be a lot of criticism. The apparent deadline for our contribution is rapidly approaching. Unless we have reached in writing an arrangement that provides suitable compensation for my time (and in my case any necessary work visas) I will have to withdraw all the material I've circulated and leave the project to others.

Cheers,
Ross

On Sat, Apr 19, 2025 at 7:12 AM Roy Spencer <roywspencer@hotmail.com> wrote:

All:

I spent a considerable amount of time last year reading/annotating/categorizing the December 7, 2009 Technical Support Document (TSD) for the CO2 Endangerment Finding. It is heavily referenced and undoubtedly involved years of work by a marching army of experts (guided, no doubt, by lawyers).

That document claimed to have 31 EPA authors, and 12 government expert reviewers. Attached is a spreadsheet with the backgrounds of each of those authors/reviewers.

Based upon their credentials, I would argue only one (Gavin Schmidt, an expert reviewer) had expertise directly relevant to the writing of the most important scientific claims in the document.

Arguably, *none of the EPA authors had the required expertise*. Many were new graduates in fields like geography. They then got promoted to management positions within the EPA.

It is for this reason that I now believe that most of the 2009 TSD was ghost-written, probably by more-expert volunteers and contractors to the two companies supporting the document preparation: Eastern Research Group, and Stratus Consulting.

This was no doubt a multi-million-dollar effort. Probably over \$10 Million.

About all I can hope is that what we write will provide sufficient "reasonable scientific doubt" regarding the science claims in the 2009 TSD, based upon almost 2 decades of new science, to call into question the original reasoning for the EPA Administrator's decision that CO2 presents a threat to human health and welfare.

It sounds like the lawyers involved believe they can win this fight without the science (lawyers and judges hate dealing with science).

But if the science argument is decided upon by a vote, or by the number of published citations, we lose the science argument.

-Roy

From: Travis Fisher

Sent: Friday, April 18, 2025 9:03 PM

To: Judith Curry

Cc: Ross McKittrick; John Christy; Roy Spencer; Steven Koonin

Subject: Re: I'll need help: 10 sections to go

Thanks so much, Judy!

Great questions. I don't think anyone has taken on the "air pollutant" issue. Please feel free to tackle it if you like!

Regarding the regulation in question, I've been told this summary of the science will be published as a technical support document relevant to a new proposed rule on tailpipe emissions standards for motor vehicles. I don't know whether that means all motor vehicles or just light- and medium-duty vehicles. It might be helpful to differentiate GHG emissions from the different classes to give the EPA flexibility in that regard.

The previous administration combined the rules for GHGs and criteria pollutants into a "multi-pollutant" rule, and I don't have any information on how this administration will package the different emissions standards. The exact charge for you all is to provide an update on the science relevant to the EPA's endangerment determination with respect to GHGs. As I understand the assignment, the scope is only GHGs, not criteria pollutants.

Keep the questions coming! I can run them up the chain if I don't know the answers, and I am happy to relay any questions you all have to the relevant folks at DOE or other agencies.

For your awareness, I was asked to share the table of contents with the EPA team this evening, which I did (the April 18 version), with the understanding that it is a one-way street (me informing them of your work so they know what's coming, not them sending feedback or micro-managing it). As I assured Steve in the early

stages of this work, scientific integrity is paramount, and I will do everything in my power to preserve every word of the document as you all write it. In fact, the EPA team asked that the document be DOE-branded, meaning our true audience is the Secretary of Energy, and he emphasized to me that he wants nothing but science. In other words, the only compromise you have to make in how this is written is among yourselves, not between you all and policymakers, lawyers, or economists.

Thanks again for lending your expertise to this effort, all of you.

Best,
Travis

On Fri, Apr 18, 2025 at 8:46 PM Judith Curry <curry.judith@gmail.com> wrote:

I have a lot of material already written that should be relevant. I have a draft of the sea level rise section completed, am sending this to my assistant to format, will upload monday.

Roy, let me know if there are sections you can't complete, i may have some text that is already written

On Fri, Apr 18, 2025 at 3:06 PM Travis Fisher <travis.scott.fisher@gmail.com> wrote:

Good afternoon,

I'm happy to report that I just talked with Judy, and she accepted the mission (in case you're wondering, the vetting issue was a mishap). This is great news because the Secretary wanted all of you to be able to contribute.

Let's make sure to include Judy in all of our correspondence from now on. The documents should be available here: https://www.dropbox.com/sc/fo/wahx6lpwzu33m5vyri8x/ANTU1qAQJ-zXCFzP_gsJcOs?rlkey=llz3qj9v46e1t5f4ywwxq7p8c&c=1&dl=0. Please let us know if you don't have access.

Best,
Travis

On Fri, Apr 18, 2025 at 4:59 PM Ross McKittrick <ross.mckittrick@gmail.com> wrote:

Thanks John. The quote from Mauritsen and Roeckner is a great addition.

I find the figure hard to follow, whereas the quote makes the point very clearly, in their own words.

On Fri, Apr 18, 2025 at 4:55 PM John Christy <climateman60@gmail.com> wrote:

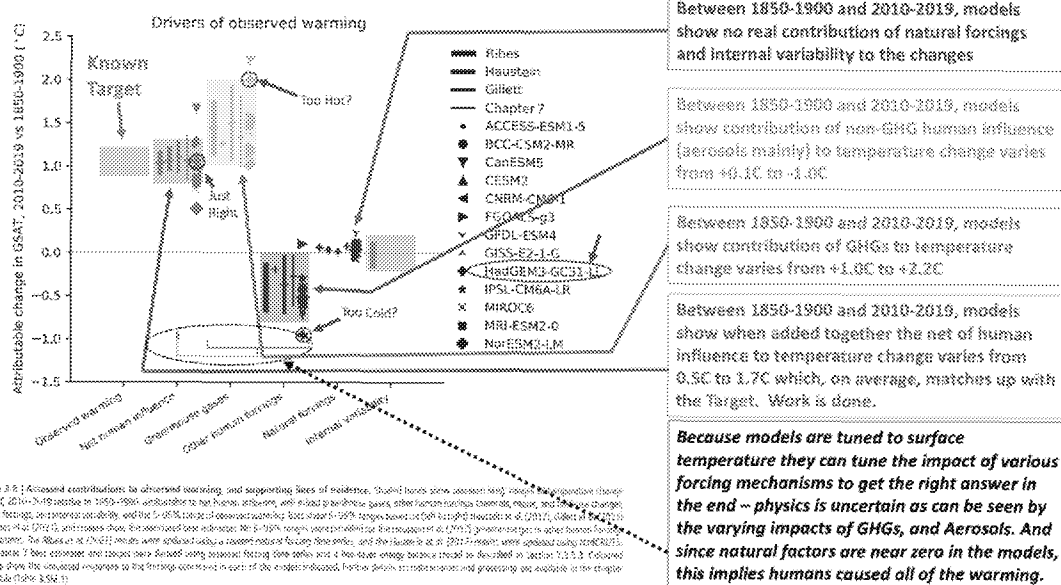
Ross

I've never been successful with dropbox and my record is still intact.

Attached is 1.6.2 to which I added a paragraph.

Also attached is a chart I annotated from AR6. I think this story demonstrates modelers are just playing with tuning parameters. Is there some way to use this information here (not necessarily in this format)?

John C.



On Fri, Apr 18, 2025 at 3:32 PM Ross McKittrick <ross.mckittrick@gmail.com> wrote:

I've uploaded a new version of Section 2.2 to your folder. It includes the earlier material quoting all the relevant IPCC and NCA17 stuff and adds some external source information I found. Still needs a brief summary. Others may have more to add.

On Fri, Apr 18, 2025 at 3:05 PM Roy Spencer <roywspencer@hotmail.com> wrote:

Ross:

Let me look early in the morning to see which ones I feel like I can knock out the fastest. Our "guidance" has been to start from "scratch", while relying on preexisting materials where it helps. I think I know why we've been told this, but it's not my place to say.

- Roy

Sent from my Verizon, Samsung Galaxy smartphone

----- Original message -----

From: Ross McKittrick <ross.mckittrick@gmail.com>

Date: 4/18/25 10:49 AM (GMT-06:00)

To: Roy Spencer <roywspencer@hotmail.com>

Cc: Travis Fisher <travis.scott.fisher@gmail.com>, Steven Koonin <steven.koonin@gmail.com>, John Christy <climateman60@gmail.com>

Subject: Re: I'll need help: 10 sections to go

Sorry Roy, I didn't mean to swamp you, I figured those were sections you already had in the can from previous work. Looking through my own folders I have some material I forgot I had written which I can repurpose. Can you send a list of the sections you are able to do, and the ones you would like to hand off for the time being?

Also to Travis' point we should look to having Judy help some of the sections. Travis, she can be reached via curry.judith@gmail.com

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Section 302 can be found [here](#).

As you all develop the draft, I encourage you to include as many citations to published materials as possible (links would work fine as placeholders). I have found this works better under a tight timeline than going back and looking for sources later. Please also feel free to task me with any research help you might need.

Best,
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To: Ross McKittrick <ross.mckittrick@gmail.com>

Cc: Travis Fisher <travis.scott.fisher@gmail.com>; steven.koonin@gmail.com; roywspencer@hotmail.com

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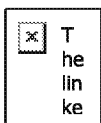
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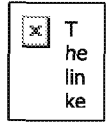
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<DE.memo.outline.Apr.11.[RM].docx>

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Judith Curry, President
CFAN - Climate Forecast Applications Network
Reno, NV USA
curry.judith@cfanclimate.com | +1.404.803.2012
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From: Ross McKitrick <ross.mckitrick@gmail.com>
Sent: Saturday, April 19, 2025 10:23 AM
To: Roy Spencer
Cc: Travis Fisher; Judith Curry; John Christy; Steven Koonin
Subject: Re: Our authorship vs. that of the EPA's 2009 EF TSD
Attachments: Fig_AR6_3.8_Apr18[JC].png

Travis, At this point I do not authorize you to share any work product I have contributed with any other group inside or outside the US government. At this point I am sharing notes with some colleagues on some topics of mutual interest in my private capacity as a non-US citizen. I am not a DoE employee or contractor and this is not a DoE work product.

I realize that people on your end have a use in mind for this material although so far no one has done us the courtesy of offering a clear explanation of exactly what we are being asked to do. I can't be expected to attach any more importance to contributing to the project than you guys attach to me being involved in it. So far, other than the original phone call recruiting me no one on your end has indicated you perceive any tangible value to having me involved. Providing a TSD to support a reassessment of the EF is very demanding and puts authors on the hook for a long time into the future to deal with what will be a lot of criticism. The apparent deadline for our contribution is rapidly approaching. Unless we have reached in writing an arrangement that provides suitable compensation for my time (and in my case any necessary work visas) I will have to withdraw all the material I've circulated and leave the project to others.

Cheers,
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On Fri, Apr 18, 2025 at 4:59 PM Ross McKittrick <ross.mckittrick@gmail.com> wrote:

Thanks John. The quote from Mauritsen and Roeckner is a great addition.

I find the figure hard to follow, whereas the quote makes the point very clearly, in their own words.

On Fri, Apr 18, 2025 at 4:55 PM John Christy <climateman60@gmail.com> wrote:

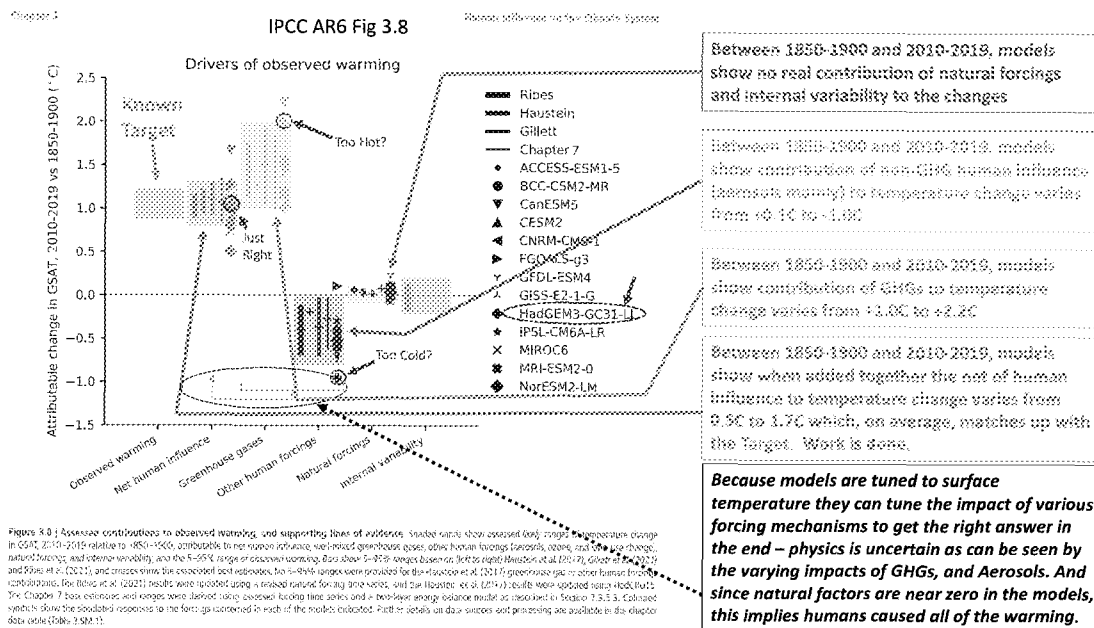
Ross

I've never been successful with dropbox and my record is still intact.

Attached is 1.6.2 to which I added a paragraph.

Also attached is a chart I annotated from AR6. I think this story demonstrates modelers are just playing with tuning parameters. Is there some way to use this information here (not necessarily in this format)?

John C.



On Fri, Apr 18, 2025 at 3:32 PM Ross McKittrick <ross.mckittrick@gmail.com> wrote:
I've uploaded a new version of Section 2.2 to your folder. It includes the earlier material quoting all the relevant IPCC and NCA17 stuff and adds some external source information I found. Still needs a brief summary. Others may have more to add.

On Fri, Apr 18, 2025 at 3:05 PM Roy Spencer <roywspencer@hotmail.com> wrote:
Ross:
Let me look early in the morning to see which ones I feel like I can knock out the fastest. Our "guidance" has been to start from "scratch", while relying on preexisting materials where it helps. I think I know why we've been told this, but it's not my place to say.
- Roy

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I think we should combine sections 1.4.3 and 1.4.4 (attached) which I now call "The carbon cycle, emissions scenarios, and global greening".

I found that all of these need to be discussed together. Feel free to reword the section title.

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I took it upon myself to write a preamble in **Section 1.3 Drivers of climate change** (attached), which seemed necessary to introduce some basic concepts.

Also attached are my initial submissions for **1.3.2** and **1.3.3**.

NO references added yet.

One of the things I believe we need to watch out for is *neglecting to come to conclusions along the way*... There is a tendency to get mired in the technical details without getting around to saying what each section might mean in eventual policy decisions related to the Endangerment Finding. In my experience, it is not possible to dumb-down this stuff too much. I suggest some sort of "Summary Boxes" with 1-2 simplified statements highlighting a main conclusion of each section that would have policy relevance.

-Roy

From: Ross McKittrick <ross.mckittrick@gmail.com>

Sent: Monday, April 14, 2025 1:37 PM

To: Travis Fisher <travis.scott.fisher@gmail.com>

Cc: Steven Koonin <steven.koonin@gmail.com>; John Christy <climateman60@gmail.com>;
roywspencer@hotmail.com <roywspencer@hotmail.com>

Subject: Re: Kickoff

Hi Travis

We developed the outline a bit further and assigned sections out yesterday. We'll keep you cc'd going forward.

Here is a Dropbox link that contains the current outline (also attached) which indicates who is working on each section

https://www.dropbox.com/scl/fo/wahx6lpwzu33m5vyrr8x/ANTU1qAQJ-zXCFzP_gsJcOs?rlkey=l1z3qj9v46e1t5f4ywwxq7p8c&dl=0

The link should give you all editing privileges.

I put folders in there for each of us. If the use of that Dropbox (which is on my own account) is acceptable for this project then we can share our work using it. Otherwise once we have an official Dropbox created we can transfer the material over to it.

Do you think it would be helpful to have a section specifically addressing the question of whether CO2 is a pollutant like CO, NOx, SOx, PM, etc.? If you want to add topics or suggest changes please do, the earlier the better as we begin filling out the contents.

Cheers,

Ross

On Mon, Apr 14, 2025 at 2:12 PM Travis Fisher <travis.scott.fisher@gmail.com> wrote:

This is an excellent start! Can we move forward by iterating with this document for now? Please feel free to add whatever material you like, and I can collate if there are any simultaneous changes. I will leave the substance to you all because I view my role as a facilitator rather than a contributor, but please let me know how I can be most helpful.

Steve is correct that this document should be clear and understandable for non-experts. My understanding is that it should also be sufficiently technical and comprehensive to inform policymakers on all relevant aspects of the science.

One area I can help with might be targeting your work for the very brief window we have open at the moment. I am including a few lines verbatim below from key documents to highlight the areas of inquiry that are most relevant to the policymaking process. Of course, you all should make your own judgments about what to include versus what to leave out.

Here is a key section of the Clean Air Act, 202(a)(1): "The Administrator shall by regulation prescribe (and from time to time revise) in accordance with the provisions of this section, standards applicable to the emission of any air pollutant from any class or classes of new motor vehicles or new motor vehicle engines, which in his judgment cause, or contribute to, air pollution which may reasonably be anticipated to endanger public health or welfare. Such standards shall be applicable to such vehicles and engines for their useful life (as determined under subsection (d), relating to useful life of vehicles for purposes of certification), whether such vehicles and engines are designed as complete systems or incorporate devices to prevent or control such pollution."

Section 202 can be found [here](#).

Here is another key section of the Clean Air Act, section 302(g): "The term 'air pollutant' means any air pollution agent or combination of such agents, including any physical, chemical, biological, radioactive (including source material, special nuclear material, and byproduct material) substance or matter which is emitted into or otherwise enters the ambient air. Such term includes any precursors to the formation of any air pollutant, to the extent the Administrator has identified such precursor or precursors for the particular purpose for which the term 'air pollutant' is used."

A threshold question raised in Justice Scalia's dissent in *Mass v. EPA* (which can be found [here](#)) is whether CO2 falls under the definition of an "air pollutant" under the Clean Air Act. The majority in *Mass v. EPA* found that *any* compound emitted into the ambient air fits the definition of "air pollutant," leading to a colorful footnote in the Scalia dissent ("It follows that everything airborne, from Frisbees to flatulence, qualifies as an 'air pollutant.' This reading of the statute defies common sense."). A scientific interpretation of this definition could be very helpful.

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11

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Subject: Our authorship vs. that of the EPA's 2009 EF TSD
Attachments: 2009-TSD-authors.xlsx

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Also attached are my initial submissions for **1.3.2** and **1.3.3**.

NO references added yet.

One of the things I believe we need to watch out for is *neglecting to come to conclusions along the way*... There is a tendency to get mired in the technical details without getting around to saying what each section might mean in eventual policy decisions related to the Endangerment Finding. In my experience, it is not possible to dumb-down this stuff too much. I suggest some sort of "Summary Boxes" with 1-2 simplified statements highlighting a main conclusion of each section that would have policy relevance.

-Roy

From: Ross McKittrick <ross.mckittrick@gmail.com>

Sent: Monday, April 14, 2025 1:37 PM

To: Travis Fisher <travis.scott.fisher@gmail.com>

Cc: Steven Koonin <steven.koonin@gmail.com>; John Christy <climateman60@gmail.com>;
roywspencer@hotmail.com <roywspencer@hotmail.com>

Subject: Re: Kickoff

Hi Travis

We developed the outline a bit further and assigned sections out yesterday. We'll keep you cc'd going forward.

Here is a Dropbox link that contains the current outline (also attached) which indicates who is working on each section

https://www.dropbox.com/scl/fo/wahx6lpwzu33m5vyrr8x/ANTU1qAQJ-zXCFzP_gsJcOs?rlkey=l1z3qj9v46e1t5f4ywwxq7p8c&dl=0

The link should give you all editing privileges.

I put folders in there for each of us. If the use of that Dropbox (which is on my own account) is acceptable for this project then we can share our work using it. Otherwise once we have an official Dropbox created we can transfer the material over to it.

Do you think it would be helpful to have a section specifically addressing the question of whether CO₂ is a pollutant like CO, NO_x, SO_x, PM, etc.? If you want to add topics or suggest changes please do, the earlier the better as we begin filling out the contents.

Cheers,

Ross

On Mon, Apr 14, 2025 at 2:12 PM Travis Fisher <travis.scott.fisher@gmail.com> wrote:

This is an excellent start! Can we move forward by iterating with this document for now? Please feel free to add whatever material you like, and I can collate if there are any simultaneous changes. I will leave the substance to you all because I view my role as a facilitator rather than a contributor, but please let me know how I can be most helpful.

Steve is correct that this document should be clear and understandable for non-experts. My understanding is that it should also be sufficiently technical and comprehensive to inform policymakers on all relevant aspects of the science.

One area I can help with might be targeting your work for the very brief window we have open at the moment. I am including a few lines verbatim below from key documents to highlight the areas of inquiry that are most relevant to the policymaking process. Of course, you all should make your own judgments about what to include versus what to leave out.

Here is a key section of the Clean Air Act, 202(a)(1): "The Administrator shall by regulation prescribe (and from time to time revise) in accordance with the provisions of this section, standards applicable to the emission of any air pollutant from any class or classes of new motor vehicles or new motor vehicle engines, which in his judgment cause, or contribute to, air pollution which may reasonably be anticipated to endanger public health or welfare. Such standards shall be applicable to such vehicles and engines for their useful life (as determined under subsection (d), relating to useful life of vehicles for purposes of certification), whether such vehicles and engines are designed as complete systems or incorporate devices to prevent or control such pollution."

Section 202 can be found [here](#).

Here is another key section of the Clean Air Act, section 302(g): "The term 'air pollutant' means any air pollution agent or combination of such agents, including any physical, chemical, biological, radioactive (including source material, special nuclear material, and byproduct material) substance or matter which is emitted into or otherwise enters the ambient air. Such term includes any precursors to the formation of any air pollutant, to the extent the Administrator has identified such precursor or precursors for the particular purpose for which the term 'air pollutant' is used."

A threshold question raised in Justice Scalia's dissent in *Mass v. EPA* (which can be found [here](#)) is whether CO₂ falls under the definition of an "air pollutant" under the Clean Air Act. The majority in *Mass v. EPA* found that *any* compound emitted into the ambient air fits the definition of "air pollutant," leading to a colorful footnote in the Scalia dissent ("It follows that everything airborne, from Frisbees to flatulence, qualifies as an 'air pollutant.' This reading of the statute defies common sense."). A scientific interpretation of this definition could be very helpful.

The next section in the statute is 302(h), which defines effects on welfare: "All language referring to effects on welfare includes, but is not limited to, effects on soils, water, crops, vegetation, manmade materials, animals, wildlife, weather, visibility, and climate, damage to and deterioration of property, and hazards to transportation, as well as effects on economic values and on personal comfort and well-

being, whether caused by transformation, conversion, or combination with other air pollutants." Positive impacts, including fertilization effects and beneficial warming, seem to be within scope here.

Section 302 can be found [here](#).

As you all develop the draft, I encourage you to include as many citations to published materials as possible (links would work fine as placeholders). I have found this works better under a tight timeline than going back and looking for sources later. Please also feel free to task me with any research help you might need.

Best,
Travis

On Fri, Apr 11, 2025 at 8:10 PM Steven Koonin <steven.koonin@gmail.com> wrote:
I assume we're writing for non-experts. If so, some educating beyond the root questions is in order (it always helps if people feel smarter after reading).

So I've taken Ross' material, added some broader context, and cast it into the forcing/response/impact syllogism that most non-experts seem to get. The result is attached.

I think we can deal with the differences relative to 2009 in an appendix.

SEK

From: John Christy <climateman60@gmail.com>
Sent: Friday, April 11, 2025 6:34 PM
To: Ross McKittrick <ross.mckittrick@gmail.com>
Cc: Travis Fisher <travis.scott.fisher@gmail.com>; steven.koonin@gmail.com; roywspencer@hotmail.com
Subject: Re: Kickoff

Excellent list Ross. Wildfires are a significant topic to be addressed.

John C.

Sent from my iPhone

On Apr 11, 2025, at 4:05 PM, Ross McKittrick <ross.mckittrick@gmail.com> wrote:

The attached represents my summary of the most questions needing to be answered, which I think this group is capable of answering in the next couple of weeks. Probably lots of material already in hand.

On Fri, Apr 11, 2025 at 4:24 PM Travis Fisher <travis.scott.fisher@gmail.com> wrote:

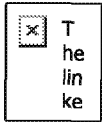
Gentlemen,

I can't thank you enough for taking this on under such a tight timeline. Let's use this thread to exchange information, links, etc., and as we move forward, I'll see about a document-sharing platform and a shared document to work on simultaneously.

Best,
Travis

<DE.memo.outline.Apr.11.[RM].docx>

--



Judith Curry, President
CFAN - Climate Forecast Applications Network
Reno, NV USA
curry.judith@cfanclimate.com | +1.404.803.2012
<http://www.cfanclimate.net>

From: Judith Curry <curry.judith@gmail.com>
Sent: Tuesday, May 13, 2025 9:35 AM
To: Roy Spencer; John Christy; Ross McKittrick; Travis Fisher; Steven Koonin
Subject: Ch 11
Attachments: 11.Managing Risks .docx

Attached is latest version (not much changed), I'm sending this to dropbox

--



Judith Curry, President
CFAN - Climate Forecast Applications Network
Reno, NV USA
curry.judith@cfanclimate.com | +1.404.803.2012
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11. Managing Risks of Extreme Weather

11.1 Socioeconomic context

Risks from human-caused climate change are convoluted with natural weather and climate variability, and are dominated by the exposure of wealth in coastal and other disaster-prone regions and vulnerabilities of poorer populations. The evolution of climate risk in the U.S. has been dominated by societal factors, rather than by changes to the actual weather and climate hazards. Deaths from weather disasters have decreased substantially since 1900, even as US population grew from 76 million in 1900 to over 331 million in 2020 (IM Gulkany, 2011). For example, the Galveston hurricane killed over 8,000 people in 1900 (0.01% of the US population), whereas the worst recent disaster, Hurricane Katrina in 2005, killed 1800 people (or 0.0006% of the US population) (NOAA, 2025; USCB, 2025).

Technological advances have substantially reduced losses from extreme weather events. Early warning systems, satellite monitoring, and improved weather forecasting have reduced deaths, although exact numbers are hard to quantify (T Deryugina and SM Hsiang, 2023). US weather forecasting has been estimated to reduce losses from weather events with an annualized benefit of \$31.5B, protecting lives, property, and supporting agriculture and transportation (NRC, 2010). Improved hurricane forecasts have reduced pre- and post-landfall spending, with annual per hurricane cost reductions estimated at \$5B (NBER, 2024).

Infrastructure improvements have contributed to substantial reductions in losses from extreme weather events. Building codes, such as those implemented in Florida after Hurricane Andrew (1992) have reduced losses by ensuring structures can withstand high winds and floods. Homes built after 2002 showed minimal damage during Hurricane Michael (2018), unlike older homes (FEMA, 2020). Sea walls, like the Galveston Seawall, protect against wave action and storm surge. The New Orleans Hurricane and Storm Damage Risk Reduction System successfully mitigated storm surge during Hurricane Isaac (2012) (BMI, 2013). Inland dams in the US help control flooding by storing excess water during heavy rains. It is estimated that the Tennessee Valley Authority (TVA) dams prevent about \$309M in annual flood damage in the TVA region and along the Ohio and Mississippi Rivers (TVA, 2025). During Hurricane Helene (2024), TVA's strategies prevented approximately \$406M in potential damages (APPA, 2024).

11.2 Data challenges

Since 1980, NOAA has provided a count of annual U.S. weather-related disasters that it estimates to have exceeded \$1Billion (inflation adjusted), showing a substantial increase starting in 2008. NOAA and other government officials have cited the upward trend in the Billion Dollar Disaster series as evidence that climate change is making extreme weather worse (R Pielke Jr., 2024). But over time, population and wealth have increased dramatically in the US, so when an extreme weather or climate event occurs, there is more damage even if there is no underlying trend in the frequency or intensity of extreme weather. Pielke Jr. (2024) demonstrates that losses per weather disaster are down by about 80% since 1980, as a proportion of GDP. Pielke Jr. (2024) also argued that in addition to relying on opaque data sources and unreported adjustments NOAA failed to normalize its Billion Dollar Disaster data series properly for changes in population exposure and

wealth. In May 2025 NOAA announced it has withdrawn the billion-dollar disaster product from publication (R Pielke Jr., 2025).

In summary, trends in losses from extreme weather and climate events are dominated by population increases and economic growth. Technological advances such as improved weather forecasting and early warning systems have substantially reduced losses from extreme weather events. Better building codes, flood defenses, and disaster response mechanisms have lowered economic losses relative to GDP. And finally, the US economy's expansion has diluted the relative impact of disaster costs, as seen in the comparison of historical and modern GDP percentages.

1. Indur M. Goklany, *Deaths from Extreme Weather Events, 1900–2010* (Washington, DC: Reason Foundation, September 2011), https://a8d50b36.delivery.rocketcdn.me/wp-content/uploads/2011/09/deaths_from_extreme_weather_1900_2010.pdf.
2. National Hurricane Center, “Costliest U.S. Tropical Cyclones Tables Updated,” *NOAA National Hurricane Center*, accessed May 8, 2025, <https://www.nhc.noaa.gov/outreach/history/>.
3. U.S. Census Bureau, Decennial Census by Decade, accessed May 8, 2025, <https://www.census.gov/programs-surveys/decennial-census/decade.html>.
4. Tatyana Deryugina and Solomon M. Hsiang, *Does the Environment Still Matter? Daily Temperature and Income in the United States*, NBER Working Paper No. 31361 (Cambridge, MA: National Bureau of Economic Research, June 2023), <https://www.nber.org/papers/w31361>.
5. National Research Council, *Adapting to the Impacts of Climate Change* (Washington, DC: The National Academies Press, 2010), <https://nap.nationalacademies.org/read/12888/chapter/2>.
6. National Bureau of Economic Research, “The Value of Improving Hurricane Forecasts,” *NBER Digest*, September 2024, <https://www.nber.org/digest/202409/value-improving-hurricane-forecasts>.
7. Federal Emergency Management Agency (FEMA), “The Role of Florida’s Building Codes in Hurricane Michael Recovery,” last updated February 13, 2020, <https://www.fema.gov/case-study/role-floridas-building-codes-2018-hurricane-michael>.
8. Battelle Memorial Institute, *Final Independent External Peer Review Report: Hurricane Isaac (2012) Assessment*, prepared for U.S. Army Corps of Engineers, New Orleans District, December 2013, <https://www.mvn.usace.army.mil/Portals/56/docs/PD/PeerReview/TCN13-003HurrIsaacAssessIEPRFinal.pdf>.
9. Tennessee Valley Authority (TVA), *Flood Management*, accessed May 8, 2025, <https://www.tva.com/environment/managing-the-river/flood-management>.
10. American Public Power Association, “TVA Flood Mitigation Strategies Prevented Approximately \$406 Million in Potential Damages,” *Public Power Current*, March 7, 2024, <https://www.publicpower.org/periodical/article/tva-flood-mitigation-strategies-prevented-approximately-406-million-potential-damages>.
11. Roger Pielke Jr., “Scientific Integrity and U.S. 'Billion Dollar Disasters',” *npj Natural Hazards* 1 (2024): Article 12, <https://www.nature.com/articles/s44304-024-00011-0>.
12. Roger Pielke Jr., “RIP NOAA's Billion Dollar Disasters,” *The Honest Broker (Substack)*, May 8, 2025, <https://rogerpielkejr.substack.com/p/rip-noaas-billion-dollar-disasters>.

From: Ross McKittrick <ross.mckittrick@gmail.com>
Sent: Tuesday, May 13, 2025 9:08 PM
To: Travis Fisher
Cc: Steven Koonin; Judith Curry; John Christy; Roy W. Spencer
Subject: Re: Process for edits & comments

Travis if you want to download a chapter and mark it up in track changes you can then email it around and I can put it in the DB.
Ross

On Mon, May 12, 2025 at 10:41 PM Travis Fisher <travis.scott.fisher@gmail.com> wrote:
Hi all,

I know some of us will spend the day tomorrow at the Heritage event or streaming it: <https://www.heritage.org/climate/event/the-sky-falling-reconsidering-the-endangerment-finding>

Very soon (probably later this week), I'll go through each chapter and offer comments regarding readability for non-experts and highlighting anything that seems out of place. What is the best way to do that? I don't seem to have edit/comment rights in Dropbox, which I think is the right approach because I'm sure I would only ruin your work.

Is it ok with you all if I send an email with an attachment once I've completed reading a chapter? My guess is I'll only have minor comments in bubbles to provide killer insights like "please spell out," "this could use more explanation," or "I don't understand this at all." Maybe I'll get bold and ask, "How does this square with [insert inferior analysis]?"

I promised you all that I won't try to change the substance at all. If that's how any of my comments come across, then I've clearly made a mistake, and you should feel free to ignore me or call me out. I intend to keep my promise and make sure you all are 100% comfortable with the report. I'm confident we'll get there, especially since we're keeping the whole effort under Secretary Wright. And the substance is truly impressive, by the way.

Attached is my read of the intro. In case you're reading on a phone or just don't want to open the file, my only comment was on the paragraph about this team not being wrapped up in the EPA process. I wrote:

You could say it's public knowledge that the EPA announced in March 2025 that it was "kicking off a formal reconsideration of the 2009 Endangerment Finding in collaboration with the Office of Management and Budget (OMB) and other relevant agencies. EPA also intends to reconsider all of its prior regulations and actions that rely on the Endangerment Finding."
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I think you can acknowledge that this effort is designed to inform the EPA's policymaking process.

If you want to reiterate your independence from EPA, especially EPA's political team, I think that's completely fair. They've been pretty hard for me to get a hold of, so even I have a level of independence that has basically happened by accident!

Best,
Travis

From: Judith Curry <curry.judith@cfanclimate.com>
Sent: Tuesday, May 13, 2025 5:56 PM
To: John Christy
Cc: Travis Fisher; Ross McKittrick; Steven Koonin; Roy W. Spencer
Subject: Re: Process for edits & comments

I suspect that it is hopeless to make the figures homogeneous/consistent. I propose going with the figs we have, and working on clear, stand alone figure captions

Maybe in our call tomorrow we can come up with a list of chapters that are close to being final, so that travis can start going through the ones that are unlikely to change much

On Tue, May 13, 2025 at 2:36 PM John Christy <climateman60@gmail.com> wrote:
Travis

To make the document look official, its graphics should be consistent in terms of labels, colors, fonts, etc. If you have someone who is a whiz with lots of time on their hands in the next 14 days I'm attaching a sample for the temperature extremes (section 8.4) for them to see what this might entail. The data are in spreadsheets with the tab being the figure number, and the idea of what they should look like is in the latest draft of chapter 8. The more systematic and consistent the plots are across all chapters, the better.

This will give your staffer an idea if he/she can do this for around 30 plots (no doubt each will require our back and forth input after seeing the first draft to satisfy our persnickety natures). This can be a heavy lift as we probably don't have all of the digital data for the charts at this point.

Let us know if you think this can work.

John C.

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Best,
Travis

From: John Christy [climateman60@gmail.com]
Sent: 5/13/2025 9:36:42 PM
To: Travis Fisher [travis.scott.fisher@gmail.com]
CC: Ross McKittrick [ross.mckittrick@gmail.com]; Steven Koonin [steven.koonin@gmail.com]; Judith Curry [curry.judith@cfanclimate.com]; Roy W. Spencer [roywspencer@hotmail.com]
Subject: Re: Process for edits & comments
Attachments: 8.4 Figs_13May_JRC.xlsx

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Best,
Travis

Fig 8.4.5

Number of days $\geq 95^{\circ}\text{F}$

Line	Dashed	Dash	Dash	solid	solid	solid	solid
	PacSW	PacNW	4Crns	NPIns	SPIns	UMidW	OhVly
1899-04	226.87	52.44	177.12	48.23	240.6	17.61	71.75
1905-10	246.06	58.9	156.64	43.43	252.04	12.52	36.88
1911-16	199.73	46.82	144.22	46.2	315.36	29.34	109.8
1917-22	249.24	60.09	161.85	63.02	287.09	19.65	73.52
1923-28	243.99	62.09	160.34	41.87	304.58	13.4	61.64
1929-34	262.64	69.52	185.1	106.45	352.83	53.69	133.09
1935-40	261.61	69.43	199.82	115.18	337.97	42.35	106.54
1941-46	226.36	52.44	167.46	52.52	279.87	14.63	74.02
1947-52	234.63	40.2	182.8	57.34	307.28	19.59	54.35
1953-58	230.37	45.29	193.15	60.83	365.82	21.53	90.8
1959-64	245.47	56.6	184.33	67.11	273.38	10.24	34.97
1965-70	248.82	60.42	157.92	54.57	234.28	8.87	29.52
1971-76	243.4	56.28	161.78	60.7	192.9	14.34	26.07
1977-82	238.95	51.77	182.54	50.11	293.96	11.52	43.48
1983-88	238.61	52.9	166.58	73.72	250.86	28.1	63.76
1989-94	233.65	52.69	176.58	41.43	200.48	5.86	25.61
1995-00	236.45	52.28	186.83	46.05	285.7	6.73	32.24
2001-06	282.35	71.74	214.31	73.19	244.03	9.83	30.58
2007-12	271.04	54.61	203.74	53.55	290.75	9.86	53.07
2013-18	292.46	72.52	200.35	41.8	246.15	3.9	15.35
2019-24	317.1	85.76	242.01	62.73	296.85	7.41	25.31

solid	solid	columns
SoEst	NoEst	US48
125.58	9.14	121.36
91.13	4.85	113.43
129.88	13.78	132.27
110.96	11	130.91
138.61	8.6	131.52
163.7	17.5	169.74
126.03	10.49	162.16
127.49	12.25	127.91
124.37	12.05	133.31
144.8	14.18	151.93
83.47	5.63	123.58
68.56	5.02	109.31
41.83	3.54	99.8
116.47	4.34	128
104.28	11	124.6
75.27	6.63	102.48
107.37	7.28	124
63.89	8.93	125.66
125.07	9.57	136.11
68.19	5.14	118.27
92.85	8.16	143.76

From: Travis Fisher <travis.scott.fisher@gmail.com>
Sent: Monday, May 12, 2025 10:42 PM
To: Ross McKittrick
Cc: Steven Koonin; Judith Curry; John Christy; Roy W. Spencer
Subject: Process for edits & comments
Attachments: 0.Intro.May1 [SEK] TF comment.docx

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Best,
Travis

Introduction

This document originated in late March 2025 when Secretary Wright assembled an independent team to write a report on issues in climate science relevant for energy policymaking, with particular focus on the question of whether carbon dioxide emissions endanger the US public. The team agreed to undertake the work on the condition that there would be no editorial oversight by the Secretary, the Department of Energy, or any other government personnel. This condition has been honored throughout the process and the writing team has worked with full independence.

The team began working in early April with a deadline of May 28. The short timeline and the technical nature of the material meant that we could not comprehensively review all topics. While the report is intended to be accessible for non-experts, we have omitted some introductory or explanatory material that can easily be accessed elsewhere. Nor have we attempted to survey entire literatures related to the topics covered. The scientific and technical material herein only samples vast literature on climate change but is, we believe, more than sufficient to establish our conclusions.

The team writing this report was not involved in, nor briefed on, any Administration plans or processes related to a potential challenge to the 2009 EPA CO₂ Endangerment Finding. We were asked, however, to include some information related to the role of US motor vehicles in global climate change, since that is an issue of relevance to the Department of Energy.

The writing team is grateful to Secretary Wright for the opportunity to prepare this report and for his support for independent scientific inquiry.

From: Judith Curry <curry.judith@gmail.com>
Sent: Wednesday, May 14, 2025 2:50 PM
To: John Christy
Cc: Ross McKittrick; Roy W. Spencer; Travis Fisher; Steven Koonin
Subject: Re: Ch 12 mortality

that works, i assume i put in the original statement

On Wed, May 14, 2025 at 11:44 AM John Christy <climateman60@gmail.com> wrote:
Ross and Judy

So, would the last sentence here read, "This pattern is evident in the global historical period, though not in the CONUS (Chapter 7), and is expected to continue with further warming.

John C.

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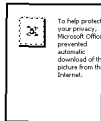
12 Mortality from temperature extremes

12.1 Heat and cold risks

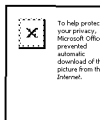
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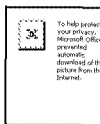
On Wed, May 14, 2025 at 10:47 AM Ross McKittrick <ross.mckittrick@gmail.com> wrote:
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From: Ross McKittrick <ross.mckitrick@gmail.com>
Sent: Wednesday, May 14, 2025 2:32 PM
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That wasn't my insertion. Suggestions for alternate wording welcome.

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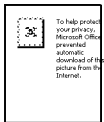
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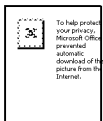
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Sent: 5/14/2025 5:46:56 PM
To: Judith Curry [curry.judith@gmail.com]; John Christy [climatemanager60@gmail.com]; Roy W. Spencer [roywspencer@hotmail.com]; Travis Fisher [travis.scott.fisher@gmail.com]; Steven Koonin [steven.koonin@gmail.com]
Subject: Ch 12 mortality
Attachments: 12.heat_cold mortality.May14[RM].docx

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{May 14 RM edits: some wording changes, removed orphan Figure 12.1, corrected Gasparini and other references

12 Mortality from temperature extremes

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Changes in temperature extremes are among the most certain impacts expected in a warming world. Extreme heat events are likely to become more frequent while extreme cold events become less frequent. This pattern is evident in the historical period (Chapter 7) and is expected to continue with further warming.

Mortality during heat extremes is typically caused by heat stroke and heat exhaustion, while mortality during cold extremes is typically caused by hypothermia and heart strain. Global mortality is substantially greater for cold conditions than for hot conditions.^{1,2} Unlike with heat-related mortality, cold-weather risks set in even at moderately cold conditions (Gasparini et al. 2015, Lee and Dessler 2023). A 13-country study of 74 million deaths from 1985 to 2012 estimated that, on average, 7.7% of deaths were attributable to sub-optimal temperatures, of which 7.4% were attributable to cold and only 0.4% were attributable to heat (Gasparini et al. 2015). In other words cold weather killed 18.5 times as many people as did hot weather.

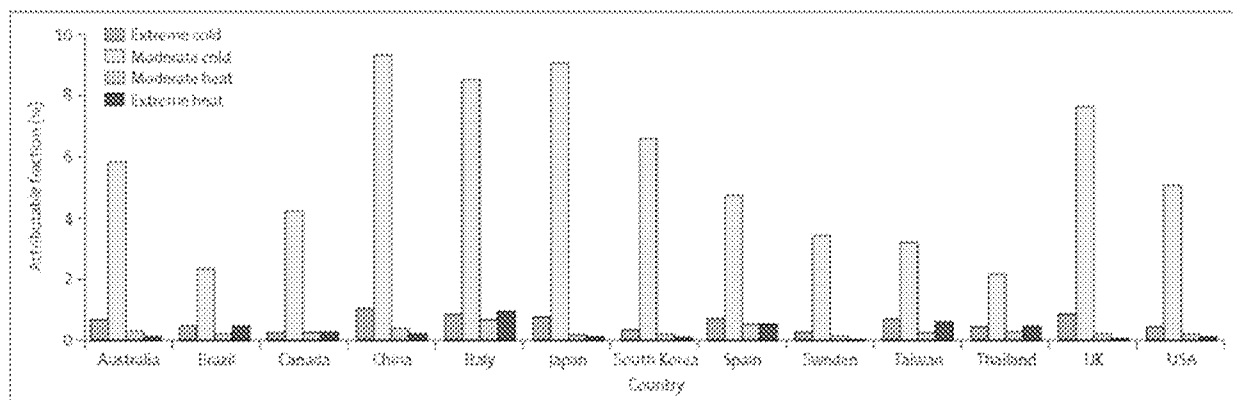


Figure 12.1. Mortality attributable to extreme and moderate cold and heat by country. Source: reproduced from Gasparini et al. (2015).

Figure 12.1 shows the distribution of results from Gasparini et al. (2015) by country. For the United States the fraction of deaths attributable to temperature was 5.9%, of which 5.5% was due to cold, thus cold weather killed 14 times as many people as hot weather.

¹ Qi Zhao et al., “Global, Regional, and National Burden of Mortality Associated with Non-Optimal Ambient Temperatures from 2000 to 2019: A Three-Stage Modelling Study,” *The Lancet Planetary Health* 5, no. 7 (July 2021), [https://doi.org/10.1016/s2542-5196\(21\)00081-4](https://doi.org/10.1016/s2542-5196(21)00081-4).

² <https://ourworldindata.org/part-one-how-many-people-die-from-extreme-temperatures-and-how-could-this-change-in-the-future>

There is strong evidence that people adapt to weather risks. Lee and Dessler (2023) reported that 86% of temperature-related deaths across 40 cities in the U.S. were due to cold-related mortality, and that due to adaptation the relative risk of death declined in hot and cold cities alike as seasonal temperatures increased. Allen and Sheridan (2018) found that short, early-season cold events were 2 to 5 times deadlier than hot events, but the mortality risk of both cold and hot extremes drops to nearly zero if the events occur late in the season.

Davis et al. (2003) examined heat-related mortality in 28 U.S. cities from the 1960s to the end of the 1990s and found that heat-related mortality declined by three-quarters over the sample period. Bobb et al. (2014) examined mortality data for 106 million people in over 100 cities U.S. cities and found a 60% decline in average heat-related mortality over the period 1987—2005, from 51 per thousand deaths to 19. They furthermore found that the greatest drop was among seniors over the age of 75. In a study of 42 million deaths in 211 U.S. cities from 1962 to 2006, Nordio et al. (2015) found a more than 90 percent decline in the risk of mortality from excess heat.

In the context of large declines in heat-related mortality, by reducing mortality from cold events rising temperatures are associated with a net saving of lives.

The IPCC AR6 Working Group 2 Chapter 16.2.3.5 states how heat-related mortality is declining over time:³

“Heat-attributable mortality fractions have declined over time in most countries owing to general improvements in health care systems, increasing prevalence of residential air conditioning, and behavioral changes. These factors, which determine the susceptibility of the population to heat, have predominated over the influence of temperature change.”

It is both disappointing and telling to see how the IPCC misrepresents the situation in its AR6 Synthesis report. Section A.2.5 of that document states: “In all regions increases in extreme heat events have resulted in human mortality and morbidity (*very high confidence*).” But it is silent on the larger decline of deaths during extreme cold events.

12.2 The importance of adaptation

The observed decline in US heat-related mortality has been specifically attributed to adaptation. Wang et al. (2018) exploited the spatial variability of heatwave-related mortality across 209 U.S. cities from 1962 to 2006. While simple correlation appeared to imply an increase in mortality risk during heatwaves, accounting for adaptation to heatwave intensity caused the effect to fall to near zero and become statistically insignificant. They used the results of their epidemiological model to project heat-related mortality out to 2050 under four RCP warming scenarios (including RCP8.5) with and without adaptive behavior. Assuming people continue to adapt to the heatwave risks in the regions in which they live Wang et al. project not only no increase in heat-related mortality but an overall decrease for the US as a whole. They conclude that “Ignoring adaptation would result in a substantial overestimate of future mortality related to heat waves... Accounting

³ B. O'Neill et al., “Key Risks Across Sectors and Regions,” in *Climate Change 2022: Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* (Geneva, CH: Intergovernmental Panel on Climate Change, 2021), 2411–2538.

for adaptation, the overall heat-related mortality by 2050 would not change substantially over time compared to 2006.”

12.3 Mortality risks and energy costs

A 2016 study of US long term mortality risks associated with temperature variations (Barreca et al. 2016) showed that increases in mortality across the US are associated both with cold weather and hot weather. But over time, the introduction of electricity and the adoption of central heating and air conditioning (AC) dramatically reduced both risks, especially those associated with hot weather. Prior to 1960, a day above 90°F (32°C) added 2.2 percent to the average mortality risk rate, but after 1960 the same weather added only 0.3 percent to mortality risk, an 85 percent reduction. Prior to 1960 temperatures below 39°F (4°C) added about 1 percent to mortality risk but after 1960 the same weather only added about half that amount. Adaptation through conventional household improvements dramatically reduced public vulnerability to weather extremes. The entire reduction in hot weather mortality was attributable to widespread adoption of indoor AC, which depended on the availability of reliable and affordable electricity.

The corollary of this finding is that the use of heating and cooling systems depends on energy being affordable. Doremus et al. (2022) showed that wealthy and poor households in the US adjust their energy expenditures at similar rates in response to moderate temperature swings, but not in response to extreme temperature swings. When temperatures swing to very cold levels (< 5°C) energy spending in high-income households rises by 1.2 percent but in low-income households by only 0.5 percent. On very hot days (>30°C) electricity spending in high-income households rises by 0.5 percent but does not change at all in low-income households. The latter result is observed even in subsamples where all households have AC. The implication is that even with widespread adoption of home heating and cooling systems, inability to afford energy leaves low-income households exposed to weather extremes.

Barreca, Alan, Karen Clay, Olivier Deschenes, Michael Greenstone, and Joseph S Shapiro, “Adapting to climate change: The remarkable decline in the US temperature mortality relationship over the twentieth century,” *Journal of Political Economy*, 2016, 124 (1), 105–159.

J.M. Doremus, I. Jacqz and S. Johnston (2022), “Sweating the energy bill: Extreme weather, poor households, and the energy spending gap.” *Journal of Environmental Economics and Management*, doi: <https://doi.org/10.1016/j.jeem.2022.102609> .

Nordio, Francesco, Antonella Zanobetti, Elena Colicino, Itai Kloog and Joel Schwartz (2015). “Changing patterns of the temperature–mortality association by time and location in the US, and implications for climate change” *Environment International*, Volume 81, pp 80-86 <https://doi.org/10.1016/j.envint.2015.04.009>.

Wang, Yan, Francesco Nordio , John Nairn , Antonella Zanobetti and Joel D. Schwartz (2018) “Accounting for adaptation and intensity in projecting heat wave-related mortality” *Environmental Research* 161 pp. 464—471. <https://doi.org/10.1016/j.envres.2017.11.049>

Bobb JF, Peng RD, Bell ML, Dominici F. (2014) Heat-related mortality and adaptation to heat in the United States. *Environmental Health Perspectives* 122:811–816; <https://ehp.niehs.nih.gov/doi/full/10.1289/ehp.1307392>

Davis, Robert E., Paul C. Knappenberger, Patrick J. Michaels and Wendy M. Novicoff (2003) “Changing Heat-Related Mortality in the United States” *Environmental Health Perspectives* 111(14) November 2003 pp. 1712—1718.

Lee, Jangho and Andrew E. Dessler (2023) Future Temperature-Related Deaths in the U.S.: The Impact of Climate Change, Demographics, and Adaptation. *Geohealth* 7(8) e2023GH000799 <https://doi.org/10.1029/2023GH000799>

Allen, M.J., Sheridan, S.C. Mortality risks during extreme temperature events (ETEs) using a distributed lag non-linear model. (2018) *International Journal of Biometeorology* 62, 57–67 (2018). <https://doi.org/10.1007/s00484-015-1117-4>

From: Ross McKittrick <ross.mckitrick@gmail.com>
Sent: Monday, May 12, 2025 5:09 PM
To: Steven Koonin
Cc: Judith Curry; John Christy; Roy W. Spencer; Travis Fisher
Subject: Re: my edits to Chapter 4

Done. I also swapped in a new version of the CO2 levels figure to make it consistent with the discussion in the greening chapter.

On Mon, May 12, 2025 at 4:47 PM Steven Koonin <steven.koonin@gmail.com> wrote:

My edits on top of Judy's.

Ross, can you please post to DropBox

Steve Koonin

From: Steven Koonin [steven.koonin@gmail.com]
Sent: 5/12/2025 8:47:06 PM
To: 'Ross McKittrick' [ross.mckittrick@gmail.com]; Judith Curry [curry.judith@cfanclimate.com]; 'John Christy' [climateman60@gmail.com]; 'Roy W. Spencer' [roywspencer@hotmail.com]; 'Travis Fisher' [travis.scott.fisher@gmail.com]
Subject: my edits to Chapter 4
Attachments: 4.AnthropogenicRF.May12 [SEK] JC[SEK].docx

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4 Human influences on the climate

4.1 Components of radiative forcing and their history

4.1.1 Historical radiative forcing

A changing climate has been the norm throughout the Earth's 4.6-billion-year history. The Earth's temperature and weather patterns change naturally over timescales ranging from decades to millions of years. Natural variations in the surface climate originate in two ways. Internal climate fluctuations associated with circulations in the atmosphere and ocean produce exchanges of energy, water, and carbon between the atmosphere, oceans, land, and ice. External influences on the climate system include variations in the energy received from the sun and the effects of volcanic eruptions. Human activities influence climate through changing land use and land cover. Humans are also changing the composition of the atmosphere by increasing emissions of CO₂ and other greenhouse gases and by altering the concentrations of aerosol particles in the atmosphere.

The earth is warmed by the sunlight it absorbs and cooled by the radiative heat it emits to space. Averaged over the Earth's surface, each of these processes involve power flows of about 240 Watts per square meter (W/m²). When they are in balance, there are no net external causes of warming or cooling. ~~Human (and some natural)~~ Both human and natural influences on the climate alter this balance and so cause the climate to change.

Influences on the Earth's energy balance at the top of the atmosphere are quantified by "radiative forcing", the extent to which they disturb the warming/cooling balance; a positive forcing warms while a negative forcing cools. The IPCC's estimated history of major components of radiative forcing since 1750 is shown in the following two figures from its AR6.

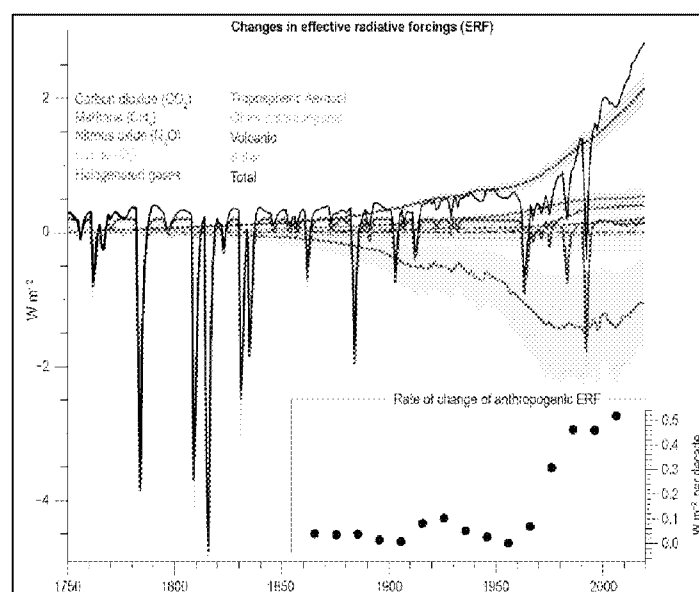


Figure 4.1.1: IPCC estimates of radiative forcing components over time. Source: <https://www.ipcc.ch/report/ar6/wg1/figures/chapter-2/figure-2-10/>

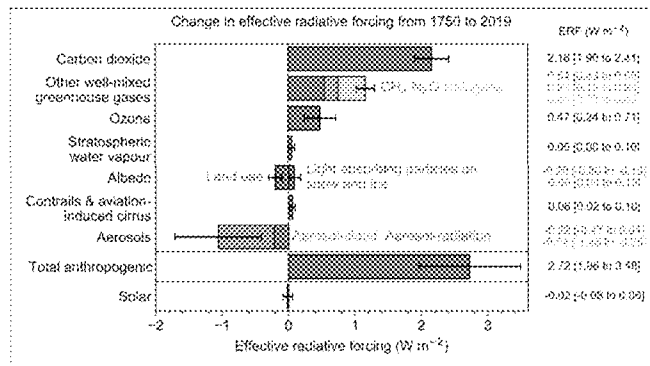


Figure 4.1.2 IPCC estimates of radiative forcing component changes from 1750 to 2019. Source: <https://www.ipcc.ch/report/ar6/wg1/figures/chapter-7/figure-7-6/>

These graphs show that the total radiative forcing is comprised of both natural and anthropogenic components. Carbon dioxide is the largest human influence on the climate and the one most relevant to the effects of energy systems like motor vehicles. It exerts a warming influence by decreasing the cooling power of the atmosphere. Emissions of CO₂ are accumulating in the atmosphere, as described in the following section, so that the warming influence is increasing. Other greenhouse gases (methane, nitrous oxide, halogens, and ozone) act similarly, currently adding another 75% to CO₂'s warming. Aerosols exert a cooling effect, although with large uncertainties in the way they catalyze the formation of reflective clouds. As a result, understanding the causes of recent warming requires not just identifying the warming effects of CO₂, but also the more uncertain cooling effects of sulfate aerosols.

The IPCC views the change in the radiative forcing by the sun to be negligible, based on their preference for reconstructions that imply minimal solar change since preindustrial times. Connolly *et al.* (2021) reviewed sixteen different Total Solar Irradiance (TSI) reconstructions in the literature covering the 1600-2000 interval; they vary from almost no change in TSI to a relatively large upward trend. Those authors note that the variation in TSI reconstructions combined with variations in surface temperature reconstructions allows for pairings that are consistent with either no or most 20th century warming being attributable to the sun. A particularly thorny issue is the gap in TSI data between 1989 and 1991 due to a delay in the launch of a monitor following the Space Shuttle Challenger disaster on January 28 1986. That prevented a replacement satellite from being launched in time to overlap with, and its readings to be intercalibrated with, the prior system (Zacharias 2014, Scafetta et al. 2019). The question of whether there is an upward trend

in TSI over 1978 to 2018 comes down to how that gap is filled. Connolly et al. (2023) found that the IPCC's consensus statements on solar forcing were prematurely formulated through the suppression of dissenting scientific opinions.

The other natural radiative forcing component is largely volcanic aerosols, which exert an episodic cooling influence. Box 4.1 in the IPCC AR6 Report addresses the climate impact of volcanic eruptions, noting three explosive volcanic eruptions that occurred in the first half of the 19th century. This included the 1815 Tambora eruption that resulted in the 'year without summer', with multiple harvest failures across the Northern Hemisphere. There is uncertainty about the sign of the relatively small forcing due to the submarine volcano Hunga Tonga which erupted in 2022 (Jenkins et al. 2023, Schoeberl et al. 2024)

The anthropogenic forcing component was negligible before about 1900 and has increased steadily since, rising to almost 3 W/m² today. However, this is still only about 1 percent of the unperturbed radiation flows, making it a challenge to isolate the effects of anthropogenic forcing; state-of-the-art satellite estimates of global radiative energy flows are only accurate to a few W/m². Natural sources of global energy imbalance other than volcanoes are not included in these graphs because they remain largely unknown.

4.1.2 Future radiative forcing

Carbon dioxide's warming influence depends upon how much "extra" CO₂ accumulates in the atmosphere- i.e., its concentration above 280 ppm. The CO₂ level as recorded at the Mauna Loa observatory in Hawaii is generally used as the representative global average concentration. The data are available online at <https://gml.noaa.gov/ccgg/trends/index.html>. The concentration was about 316 ppm at the start of the record in 1959 and is now about 425 ppm, a 34 percent increase.

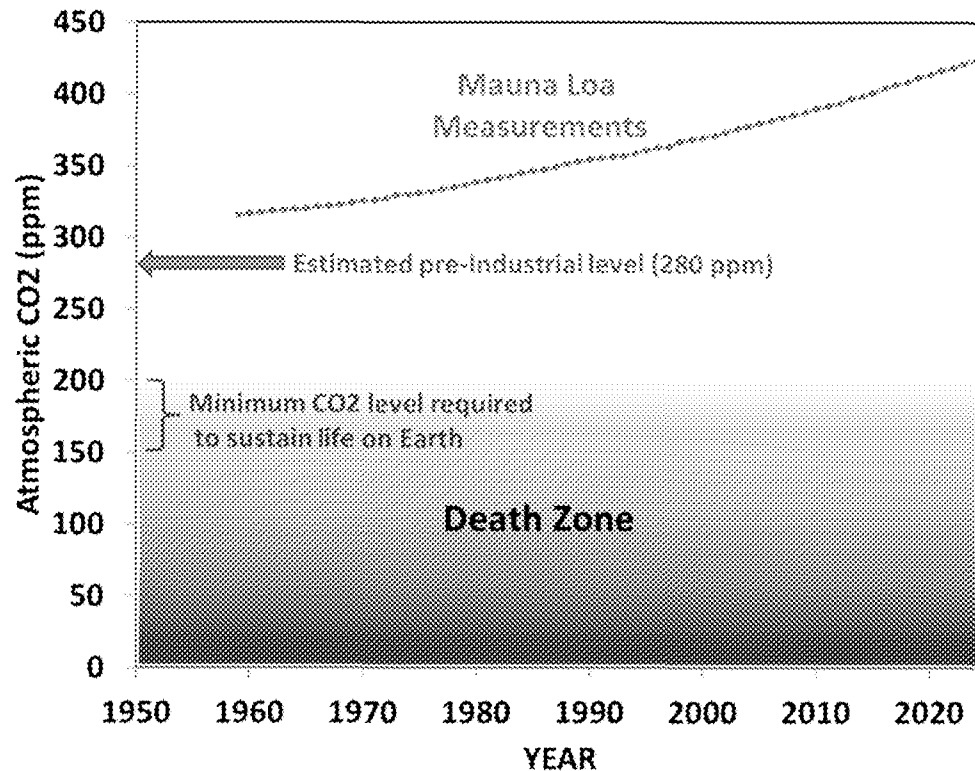


Fig. 4.1.3 Yearly average atmospheric CO₂ concentrations (1959-2024) measured at Mauna Loa, HI (green) compared to the estimated pre-Industrial CO₂ concentration of 280 ppm, and the estimated minimum levels required to sustain life on Earth (150 to 200 ppm). Need source

The annual increase in concentration is only about half of the CO₂ emitted because land and ocean processes absorb “excess” CO₂ at a rate approximately 50% of the human emissions. Future concentrations, and hence future human influences on the climate, therefore depend upon two components: (1) future rates of global human CO₂ emissions, and (2) how fast the land and ocean remove extra CO₂ from the atmosphere. We discuss each of these in turn.

4.2 Future emission scenarios and the carbon cycle

4.2.1 Emission scenarios

Assessing the dangers of future GHG emissions requires assumptions about what those emissions will be. Future emissions, and hence human influences on the climate, will depend upon future

demographics, economic progress, regulation, and the energy and agricultural technologies in use. Various assumptions about each of those lead to projections of greenhouse gas emissions and concentrations, aerosol concentrations, and changes in land use, which ultimately can be combined into assumptions about anthropogenic radiative forcing.

Because of the great uncertainties about these many factors in the decades to come, instead of making precise predictions of future concentrations, the IPCC has created various sets of scenarios meant to span a plausible range of possibilities for population, economy, technology, and so on. Recent versions of the scenarios are labeled by a number indicating the anthropogenic radiative forcing expected in 2100 under that scenario. Thus, a scenario labeled with a “6” corresponds to 6 W/m² of human-induced radiative forcing (warming) at the end of the century. (Recall current anthropogenic radiative forcing is about 2.7 W/m².)

Although the IPCC does not put its emission scenarios forward as forecasts, they are often treated as such. Comparisons of past scenario groups against observations shows a tendency for IPCC emission projections to overstate actual subsequent emissions. For the IPCC Third and Fourth Assessment Reports a set of emission projections from the *Special Report on Emission Scenarios* were used and hence were referred to as the SRES scenarios. McKittrick *et al.* (2012) showed that, when converted to per capita terms, the SRES scenario emissions distribution was skewed upwards and incompatible with observed trends. McKittrick and Wood (2013) further showed that global energy market dynamics constrained global per capita CO₂ emissions to an extent not reflected in IPCC scenarios. The bias of the SRES scenarios was confirmed by the later analysis of Hausfather *et al.* (2019) who showed that observed atmospheric CO₂ concentrations tracked the low end of the SRES range.

For the Fifth Assessment Report the IPCC developed a new set of scenarios called the Representative Concentration Pathways (RCP). These were identified by a number representing the increase in forcing and were thus called RCP2.6, RCP4.5, RCP6.0 and RCP8.5. RCP2.6 (implying an anthropogenic radiative forcing in 2100 of 2.6 W/m²) projects a GHG concentration pathway leading to warming well below 2°C. At the other end of the scale RCP8.5 is an extreme outcome implying nearly 5°C warming just in this century.

RCP8.5 came to be referred to as the no-policy baseline, or “business-as-usual” scenario in both the academic literature and popular media. It was therefore used to generate the reference outcome supposedly representing the 21st century world in the absence of emission reduction policies. But RCP8.5 was intended as a low-probability high emissions scenario and its usage as a business-as-usual baseline has been criticized as grossly misleading.¹ Hausfather and Peters (2020) writing in a commentary in *Nature* magazine, pointed out that RCP8.5 was developed as

¹ This extreme scenario is useful for modelers, since a large forcing generates a large response (warming) making it easier to assess a model’s sensitivity. But that’s very different than claiming it is a plausible future.

an extreme worst-case, and its misuse as a “business as usual” baseline has resulted in a large number of misleading studies and media reporting.

The implausibility of the RCP8.5 scenario was examined by Burgess *et al.* (2021). They noted that RCP8.5 has already diverged from observed trends in energy use and the near future trends diverge sharply from those of the International Energy Agency (IEA), which provides market-based projections of energy use for coming decades. The IEA trends, which are based on plausible extrapolations of current economic and demographic trends, run below the entire envelope of RCP projections, implying not only that RCP8.5 is dubious, but that even lower emission scenarios are looking unlikely.

Widespread use of RCP8.5 has created an alarmist bias in the climate impacts literature. The extent of this problem was confirmed in a literature analysis by Pielke Jr. and Ritchie (2020). They found ~~(p. 32)~~ that some 16,800 scientific papers published between 2010 and 2020 used the RCP8.5 scenario, with about 4,500 of the articles (p. 16) linking RCP8.5 to the concept of “business-as-usual”. Their analysis showed how RCP8.5 was misused not only by individual researchers, but also by influential science agencies like the IPCC and the US National Climate Assessment (USNCA), which has directly led to misleading coverage in prominent media outlets.

Pielke and Ritchie (2020) reported new studies using RCP8.5 were appearing in the literature at a rate of about 20 per day, with about two per day specifically linking RCP8.5 and “business as usual.” They conclude (p. 34) that the climate research community has spent a decade “committing scientific resources to science fiction” and that “The scientific literature has become imbalanced in an apocalyptic direction.” ~~(emphasis added)~~:

The IPCC developed a new set of scenarios for AR6, ~~later converted the RCP scenarios to the~~ “Shared Socioeconomic Pathway” or SSP scenarios, but these have continued the pattern of bias shown with the RCP and SRES scenarios. Figure 3.1.4 was generated using the Resources for the Future Global Energy Outlook tool (RFF 2025). The black line shows total global observed CO₂ emissions compiled by the International Energy Agency (IEA). The solid green line is the emission trajectory developed by BP Energy taking account of current emission control policies and global energy use outlooks. It overlaps a solid black line which represents the emission projection from the IEA also taking account of energy use projections and current policies. The dashed lines show the range of IPCC SSP scenarios. As of 2023, global CO₂ emissions have been tracking well below the SSP scenarios especially the two highest ones (SSP5-8.5 and SSP3-7.0).

Carbon dioxide emissions (Million metric tons), by Outlooks & Scenarios. Filtered by Region: World; Fuel: All; Outlook: 2023 Shell (Sky 2050).

Source: RFF Global Energy Outlook at www.rff.org/geo

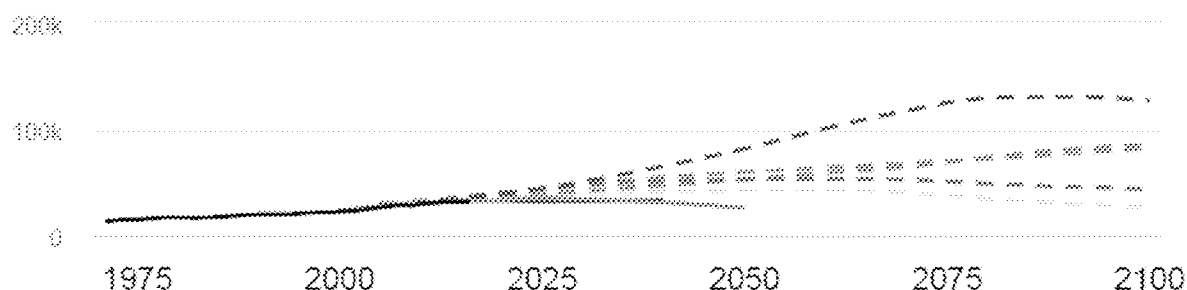


Figure 4.2.1. Observed and projected CO₂ emissions. Source: RFF (2025).

4.2.2 The carbon cycle relating emissions and concentrations

Global carbon cycle models relate concentrations to emissions using estimates of various land and ocean processes that remove CO₂ from, and emit CO₂ into, the atmosphere. Our understanding of these processes was reviewed by Crisp et al. (2021). The natural fluxes of CO₂ in and out of the Earth's surface are an order of magnitude larger than anthropogenic emissions, but those CO₂ sources and sinks were assumed to be in approximate balance in pre-industrial times, as inferred from relatively constant levels of atmospheric CO₂ found in air bubbles trapped in ice cores. This is one of several reasons why increasing atmospheric CO₂ levels are believed to be dominated by anthropogenic sources.

Specifically, fossil fuel burning (and to a lesser extent land use [biomass burning] and cement production) has led to steadily increasing CO₂ levels in the atmosphere, as shown in Fig. 1.2.1. CO₂ emissions from fossil fuel burning is a small fraction of the natural carbon cycle components. About 44,000 Gigatonnes of carbon-equivalent (GtC) are stored in the atmosphere and oceans, mostly in the form of CO₂. (Ciais et al. 2013). Between 150 and 200 GtC are released naturally each year through oceanic outgassing and land-based processes like plant decay and animal respiration. A variable but roughly equivalent amount is absorbed each year by the land and oceans, with a small net loss from the atmosphere because the formation of deep ocean sediment sequesters some carbon permanently. Global fossil fuel consumption and cement manufacture released about 10.3 GtC in 2023, up from 6.2 GtC in 1990 (Ritchie et al.

2024). Of this, about half is naturally sequestered through plant growth and oceanic uptake while the remainder, about half, adds to the atmospheric stock (Ciais et al. 2013).

As noted, each year natural processes remove a net amount of CO₂ equivalent to about 50% of global emissions. Thus, anthropogenic CO₂ emissions average twice what is required to explain the atmospheric rise in CO₂ concentration. The near-constancy of that 50% fraction (the “airborne fraction”) also means that the more CO₂ humanity produces, the faster Nature removes it from the atmosphere. That 50% fraction changes somewhat from year to year due to natural carbon cycle imbalances from El Nino, La Nina, and varying weather patterns. There was also a substantial additional reduction in atmospheric CO₂ after the 1991 eruption of Mt. Pinatubo, a curious result that has yet to be explained (Angert et al., 2004).

The main processes that remove excess CO₂ from the atmosphere are increased growth of land vegetation (especially at high latitudes), some increase in the sequestering of carbon in soils, and uptake of CO₂ by the ocean due to the increasing partial pressure of atmospheric CO₂ over that of CO₂ dissolved in the ocean. All twenty land carbon cycle models tracked by the Global Carbon Project (Friedlingstein et al., 2024) show land processes have been removing excess CO₂ at an increasing rate since 1959. This is consistent with a “global greening” phenomenon observed by satellites since monitoring of global greenness began in the 1982. This greening has been traced to CO₂ fertilization and greater drought tolerance of plants exposed to elevated CO₂ levels. While there had been some uncertainty whether a greening trend continued beyond 2000, the most recent research (Chen et al., 2023) has shown continued greening, with even some slight acceleration since 2000. Global greening is discussed further in Section 3.1.

While land vegetation has been responding positively to more atmospheric CO₂, uptake of extra CO₂ by ocean biological processes remains too uncertain to be reliably measured. Our current understanding of these and many more carbon cycle processes was reviewed by Crisp et al. (2021).

Public policy can only change the rate of emissions, not the concentration in the atmosphere. For criteria air contaminants the rate and concentration are closely connected because the lifetime is short and the concentration is small - when emissions are reduced the local pollution concentration drops rapidly, usually within a few days. But the global average CO₂ concentration behaves very differently, since carbon cycle is vast and slow. A change in local emissions today will have only a very small global effect, and even that only with a long delay. After a pulse (release) of CO₂ emissions to the atmosphere only about 40 percent ($\pm 15\%$) of the extra CO₂ will have been sequestered after twenty years. After a thousand years about 75 percent ($\pm 10\%$) will have been sequestered, and the remainder will be gradually removed over the ensuing tens of thousands of years (Ciais et al. 2013, pp. 472-473). Consequently, it will take decades or centuries for U.S. CO₂ emission reductions to have a meaningful impact on the global CO₂ concentration.

To reduce the atmospheric stock of CO₂, assuming the entire increase is anthropogenic, would require emissions to fall below the natural sequestration rate. Since that rate has been averaging about 50% of emissions, a reduction of global emissions by 50% would (at least temporarily) halt the rise in atmospheric CO₂. The 1997 Kyoto Protocol proposed to cap industrial nations' CO₂ emissions at a modest five percent below 1990 levels by the year 2012. Even though this policy ended up being too costly for most nations to implement, full compliance would not have substantially reduced atmospheric CO₂ levels. It would only have slightly slowed CO₂ growth, reaching the projected 2100 level in 2105 instead (Wigley 1998). Similarly, Lomborg (2016) used the widely-used MAGICC climate model and showed that full compliance with the Paris Accord would not stop warming, it would only prevent about 0.1C warming and delay hitting the baseline year 2100 temperature levels by about a decade.

Thus, in contrast with conventional air pollution control, even drastic local actions have minimal local effects, and only with a long delay. The practice of referring to unilateral US reductions as “combatting climate change” or “taking action on climate” reflects a profound misunderstanding of the scale of the issue. The scale problem is compounded by recognizing that U.S. motor vehicles account only for about 4 percent of global CO₂ emissions so that even a fifty percent reduction in those emissions would have a vanishingly small effect on the global climate.

Summary

- The global climate is naturally variable. Anthropogenic CO₂ emissions add to that variability by changing the total radiative balance in the atmosphere.
- The IPCC has downplayed the role of the sun in climate change but there are Total Solar Irradiance reconstructions that imply it might have been important, and the modern record is uncertain due to an interruption in satellite coverage.
- ~~Projections of anthropogenic emissions are combined with carbon cycle model estimates of atmospheric CO₂ removal to estimate future CO₂ concentrations and hence the radiative forcings. These are input to climate models to estimate future anthropogenic changes in the climate.~~
- IPCC emission scenarios have tended to exceed observed trends.
- The vast majority of academic climate “impacts” studies in recent years are based upon the extreme RCP8.5 scenario that is considered implausible; its usage as a business-as-usual scenario is misleading.
- Despite ample evidence that scenario envelopes are exaggerated, and despite criticism of this practice in the peer-reviewed literature, the IPCC's most recent scenario set (SSP) perpetuates this malpractice.

- The global carbon cycle heavily dampens the effect of changes in local (e.g. U.S.) CO₂ emissions. Even global-scale emission reductions will have only small, much delayed effects.
- ~~Knowing the magnitude of CO₂ warming requires knowing the strength of aerosol cooling. While that is uncertain, a substantial body of recent evidence points to it being relatively weak, implying CO₂ warming is likewise weak. THIS IS AN ATTRIBUTION STATEMENT~~

Scaffeta, Nicola, Richard C. Willson, Jae N. Lee and Dong Wu (2019) Modeling Quiet Solar Luminosity Variability from TSI Satellite Measurements and Proxy Models during 1980–2018. *Remote Sensing* 11(21) 2569 <https://doi.org/10.3390/rs11212569>

Connolly, Roman, Willie Soon, Michael Connolly et al. (2021) How much has the Sun influenced Northern Hemisphere temperature trends? An ongoing debate *Research in Astronomy and Astrophysics* 21(6) doi: 10.1088/1674-4527/21/6/131 <https://iopscience.iop.org/article/10.1088/1674-4527/21/6/131>

Zacharias, Pia (2014) An Independent Review of Existing Total Solar Irradiance Records. *Surveys in Geophysics* 35 pp. 897—912 <https://link.springer.com/article/10.1007/s10712-014-9294-y>

Liu, Pengfei et al. (2021) “Improved estimates of preindustrial biomass burning reduce the magnitude of aerosol climate forcing in the Southern Hemisphere” *Science Advances* 7(22) May 2021 <https://doi.org/10.1126/sciadv.abc1379>

Wang, C., Soden, B. J., Yang, W., & Vecchi, G. A. (2021). Compensation between cloud feedback and aerosol-cloud interaction in CMIP6 models. *Geophysical Research Letters*, 48, e2020GL091024. <https://doi.org/10.1029/2020GL091024>

Jenkins, S., Smith, C., Allen, M. et al. Tonga eruption increases chance of temporary surface temperature anomaly above 1.5 °C. *Nat. Clim. Chang.* 13, 127–129 (2023). <https://doi.org/10.1038/s41558-022-01568-2>

Schoeberl, M.R., Y. Wang, G. Taha, D.J. Zawada, R. Ueyama and A. Dessler, 2024. Evolution of the climate forcing during the two years after the Hunga Tonga-Hunga Ha’apai eruption. *J. Geophys. Res.*, 129, <https://doi.org/10.1029/2024JD041296>

From: Judith Curry <curry.judith@gmail.com>
Sent: Thursday, May 1, 2025 2:16 PM
To: Steven Koonin
Cc: Ross McKittrick; John Christy; Roy W. Spencer; Travis Fisher
Subject: Re: my edits of section 1

This looks fine to me.

On Thu, May 1, 2025 at 10:49 AM Steven Koonin <steven.koonin@gmail.com> wrote:

See attached. An important comment indicated is that we stick to scientific issues, not legal ones.

SEK

From: Judith Curry <curry.judith@gmail.com>
Sent: Thursday, May 1, 2025 12:48 PM
To: Steven Koonin <steven.koonin@gmail.com>
Cc: Ross McKittrick <ross.mckittrick@gmail.com>; John Christy <climateman60@gmail.com>; Roy W. Spencer <roywspencer@hotmail.com>; Travis Fisher <travis.scott.fisher@gmail.com>
Subject: Re: Intro blurb

Text looks good, but i would call this a Foreword (not Introduction)

On Thu, May 1, 2025 at 9:29 AM Steven Koonin <steven.koonin@gmail.com> wrote:

Since this was at the top of my inbox, I took a crack at some edits (attached). Generally tightening the language.

From: Ross McKittrick <ross.mckittrick@gmail.com>
Sent: Thursday, May 1, 2025 12:07 PM
To: Judith Curry <curry.judith@gmail.com>; Steven Koonin <steven.koonin@gmail.com>; John Christy <climateman60@gmail.com>; Roy W. Spencer <roywspencer@hotmail.com>; Travis Fisher <travis.scott.fisher@gmail.com>
Subject: Intro blurb

I took a stab at an intro - see attached (also in the 00.draft folder).

--

Judith Curry, President

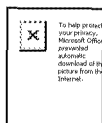
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--



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<http://www.cfanclimate.net>

From: Steven Koonin <steven.koonin@gmail.com>
Sent: Thursday, May 1, 2025 1:49 PM
To: 'Judith Curry'
Cc: 'Ross McKittrick'; 'John Christy'; 'Roy W. Spencer'; 'Travis Fisher'
Subject: my edits of section 1
Attachments: ~WRD0001.jpg; 1 CO2.v.CACs.April29 [SEK].docx

See attached. An important comment indicated is that we stick to scientific issues, not legal ones.

SEK

From: Judith Curry <curry.judith@gmail.com>
Sent: Thursday, May 1, 2025 12:48 PM
To: Steven Koonin <steven.koonin@gmail.com>
Cc: Ross McKittrick <ross.mckittrick@gmail.com>; John Christy <climateman60@gmail.com>; Roy W. Spencer <roywspencer@hotmail.com>; Travis Fisher <travis.scott.fisher@gmail.com>
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Subject: Intro blurb

I took a stab at an intro - see attached (also in the 00.draft folder).

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1 Carbon dioxide as pollutant

This report is chiefly concerned with carbon dioxide (CO₂) emissions from fossil fuel use. In 2007, the Supreme Court ruled that GHGs (CO₂ among them) were “pollutants” subject to regulation under that Clean Air Act. That framework defines six types of so-called Criteria Air Contaminants (EPA, undated): particulate matter, ground-level ozone, Sulfur Dioxide, Nitrogen Dioxide, Lead and carbon monoxide (CO).

While the definition of “pollutant” is ultimately a legal one, there are important scientific distinctions between CO₂ and the Criteria Air Contaminants. The latter are subject to regulatory control because they cause local problems depending on concentrations that include nuisances (odor, visibility problems), damage to plants and, at high enough exposure levels, toxicological effects in humans. In contrast, CO₂ is odorless, does not affect visibility and has no toxicological effects at ambient levels. It is a naturally-occurring part of the atmosphere and a key component of human and plant respiration. CO₂ is essential for plant photosynthesis and higher levels are generally considered beneficial for vegetation. In these aspects, it is similar to water.

Ambient outdoor air today contains about 420 parts per million (ppm) CO₂, increasing at about 2 ppm per year. The US Occupational Safety and Health Administration issues guidelines for indoor workplaces in which elevated CO₂ might be encountered, such as where dry ice is used. The Permissible Exposure Limit is 5,000 ppm over 8 hours (OSHA 2024). Allen *et al.* (2015) reported evidence of diminished performance on some cognitive tasks among workers in office cubicles when exposed to CO₂ levels above 1,000-1,500 ppm. These levels are far larger than any plausible value through the end of the 22nd century.

The growing amount of CO₂ in the atmosphere directly influences the earth system by promoting plant growth (global greening), thereby enhancing agricultural yields, and also by neutralizing ocean alkalinity. But the primary concern about CO₂ is its role as a greenhouse gas (GHG), that alters the earth’s energy balance. How the climate will respond to that influence is a complex question that will occupy much of this report.

US Environmental Protection Agency (Undated) Criteria Air Pollutants. <https://www.epa.gov/criteria-air-pollutants> accessed April 29 2025.

US Occupational Health and Safety Administration (2024) “OSHA Occupational Chemical Database: Carbon Dioxide” <https://www.osha.gov/chemicaldata/183>

Allen, Joseph G, Piers MacNaughton, Usha Satish, Suresh Santanam, Jose Vallarino and John D.S. Spengler (2015) Associations of Cognitive Function Scores with Carbon Dioxide, Ventilation, and Volatile Organic Compound Exposures in Office Workers: A Controlled Exposure Study of Green and Conventional Office Environments. *Environmental Health Perspectives* 124(6) pp. 805-812 <https://doi.org/10.1289/ehp.1510037>

From: John Christy [climateman60@gmail.com]
Sent: 5/12/2025 6:11:41 PM
To: Ross McKittrick [ross.mckittrick@gmail.com]
CC: Judith Curry [curry.judith@gmail.com]; Steve Koonin [steven.koonin@gmail.com]; Roy W. Spencer [roywspencer@hotmail.com]; Travis Fisher [travis.scott.fisher@gmail.com]
Subject: Re: Ch 8 Extreme weather - new thread

Reading this thread from the 158th meridian is very interesting. I'm not sure where things are (will this be a new thread if it is chapter 7?)

I forgot to include the label for "Four Corners". Attached is correct plot.

I wrote the following but am not pleased with it as the conclusion to the Ext Precipitation section. It's rather weak, especially given the analysis Ross performed on the updated datasets:

"In most regions and perhaps all, it is our opinion that the very nature of the erratic and episodic character of extreme precipitation events renders the discovery of statistically significant changes, including a relationship to CO2 concentrations, a result yet to be achieved (McKittrick and Christy 2019)."

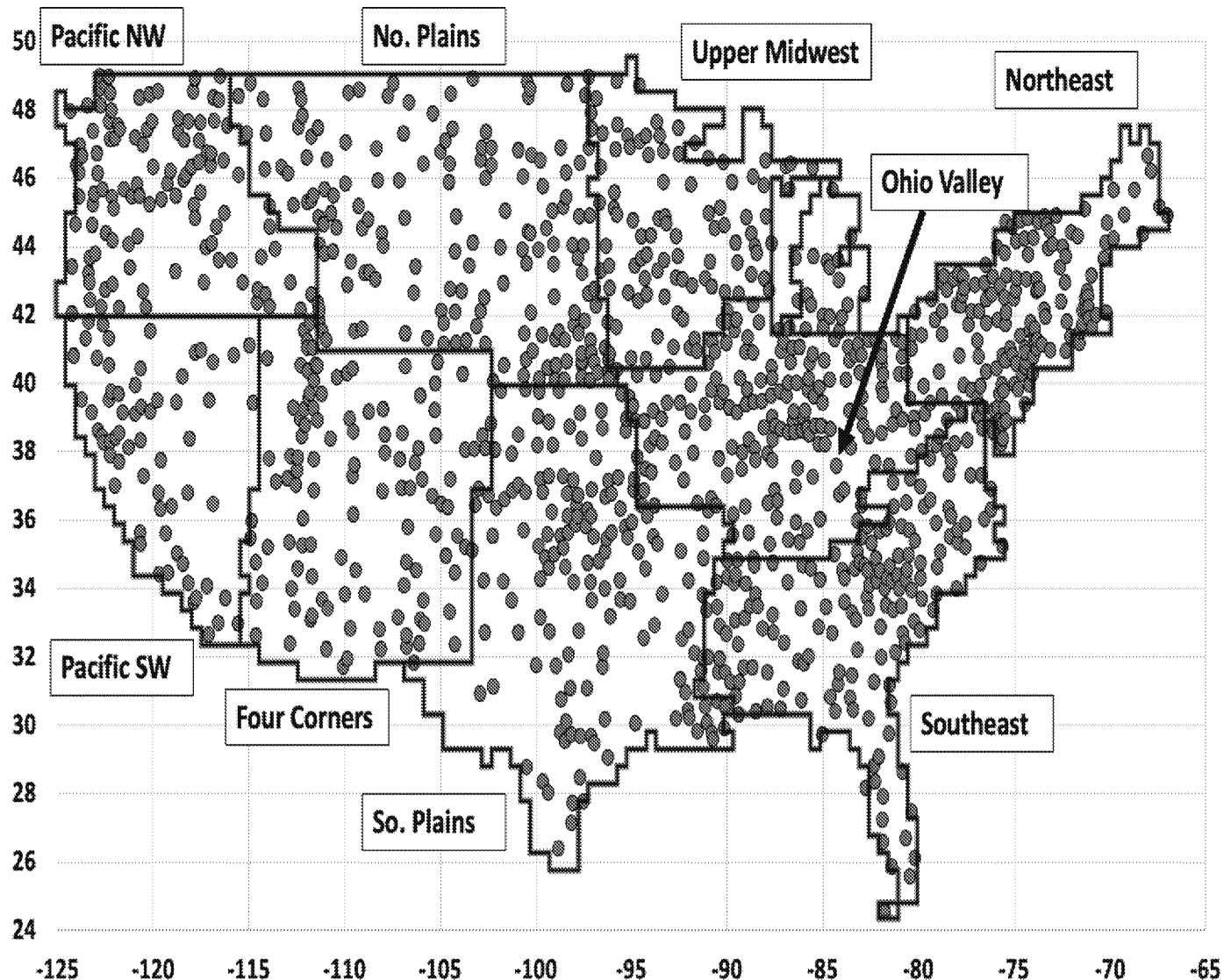
Try this?

Recognizing that the nature of extreme precipitation events is erratic and episodic, the updated CONUS-wide information provided here indicates that significant trends have not been detected (McKittrick and Christy 2019).

I will look at this again when I land in Huntsville Tuesday.

John C.

John Christy
Director, Earth System Science Center
Professor, Atmos and Earth Science
Alabama State Climatologist
The University of Alabama in Huntsville
climateman60@gmail.com



On May 12, 2025, at 12:00 PM, Ross McKittrick <ross.mckitrick@gmail.com> wrote:

That could work. The flow will be a bit choppy whichever order we have them in but maybe the attribution chapter should go at the end of Part II, i.e.

Part II: Climate response to greenhouse gas emissions

5 Measuring climate sensitivity to CO2 doubling

6 Models versus observations in recent past

7 Observed changes in extreme weather

8 Sea level rise

9 Uncertainties in analysis of attribution

On Mon, May 12, 2025 at 12:40 PM Judith Curry <curry.judith@gmail.com> wrote:

another suggestion is that i think it makes sense to switch the order of chapters 7 and 8 (detection before attribution)

On Mon, May 12, 2025 at 9:28 AM Ross McKittrick <ross.mckittrick@gmail.com> wrote:

Perhaps we could fill in a bit more detail about the categories in Table 12.12 in Section 7.4 where the discussion naturally belongs. Then in Ch 8 what about reducing 8.2 to something like this:

8.2 Context: detection is not attribution

This chapter is concerned with detection of trends. Chapter 7 looked at causal attribution, with Section 7.4 specifically addressing extreme weather. If no trend is detected then clearly there is no basis for attribution. But even where a trend is observed attribution should not be assumed automatically to follow. Since there is considerable public interest in the question of whether humans are causing trends in extreme weather to get worse it is useful to recall that AR6 Table 12.12 indicates that, for 34 major weather event and impact types, detection of an anthropogenic signal is asserted with high confidence in only four of the 34 weather impact categories, and with medium confidence in a further four. The IPCC does not claim to have detected an anthropogenic signal in the remaining 26 categories. Of the four high confidence assertions, two are for changes in average temperatures (air and ocean), which are not measures of extreme weather. Also two of the four medium confidence assertions are related to ocean chemistry and are also not related to extreme weather. The IPCC does not assert a detectable human influence on many non-temperature weather features such as wind, precipitation, flooding, and drought.

On Mon, May 12, 2025 at 12:12 PM Judith Curry <curry.judith@gmail.com> wrote:

This is a good compromise, but technically the first column is detection and attribution

On Mon, May 12, 2025 at 8:33 AM Steven Koonin <steven.koonin@gmail.com> wrote:

I think we should still lead with a truncated version of the table. It is very powerful that even IPCC sees no trend in most impact drivers. So omit the "emerging by 2050" and "emerging by 2100" columns. That way it's only about detection.

SEK

PS Of course, need to note this truncation in the Table caption.

From: Judith Curry <curry.judith@gmail.com>

Sent: Monday, May 12, 2025 10:09 AM

To: Ross McKittrick <ross.mckittrick@gmail.com>

Cc: John Christy <climateman60@gmail.com>; Roy W. Spencer <roywspencer@hotmail.com>; Travis Fisher <travis.scott.fisher@gmail.com>; Steven Koonin <steven.koonin@gmail.com>

Subject: Re: Ch 8 Extreme weather - new thread

several comments

I don't like table 12.12 in this chapter, since the chapter is about detection -- not attribution and not projections (and I detest showing extreme emissions scenario)

The general idea of this re-organization is good

I would lead with temperature extremes and then precip extremes, since the IPCC has actually detected a change in these

I will redo the hurricane one (ryan maue's figure is good but i have other suggestions)

On Sun, May 11, 2025 at 8:28 PM Ross McKittrick <ross.mckittrick@gmail.com> wrote:

Here is a suggested version that might work ...

Taking Judy's reduced collection of excerpts I put each one at the start of its section so that any contextual discussion occurs right away. To make these easier to find I pasted them from Judy's document in gray text. I added in the NCA17 heat wave chart. I also put the IPCC Table 12.12 in with an explanation that it's not strictly speaking trend detection and we did attribution in Ch 7 but it's still helpful context.

The chapter sequence is:

8.1 Introduction

8.2 IPCC Table 12.12

8.3 hurricanes and TCs

8.4 Temperature extremes

8.5 Extreme precip

8.6 Tornadoes

8.7 Flooding

8.8 Droughts

8.9 Wildfires

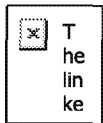
8.10 Summary

I took out the AI-generated summary that was in previously since it seemed overly focused on Table 12.12.

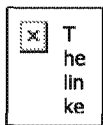
--

<~WRD0001.jpg>

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From: Judith Curry <curry.judith@gmail.com>
Sent: Monday, May 12, 2025 1:56 PM
To: Ross McKittrick
Cc: Steven Koonin; John Christy; Roy W. Spencer; Travis Fisher
Subject: Re: Ch 8 Extreme weather - new thread

I like this reorganization

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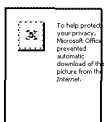
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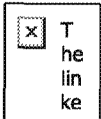
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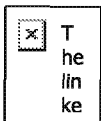
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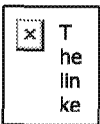
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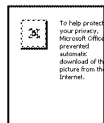
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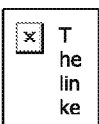
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Cc: 'John Christy'; 'Roy W. Spencer'; 'Travis Fisher'
Subject: RE: Ch 8 Extreme weather - new thread
Attachments: ~WRD0001.jpg

I think we should still lead with a truncated version of the table. It is very powerful that even IPCC sees no trend in most impact drivers. So omit the "emerging by 2050" and "emerging by 2100" columns. That way it's only about detection.

SEK

PS Of course, need to note this truncation in the Table caption.

From: Judith Curry <curry.judith@gmail.com>
Sent: Monday, May 12, 2025 10:09 AM
To: Ross McKittrick <ross.mckittrick@gmail.com>
Cc: John Christy <climateman60@gmail.com>; Roy W. Spencer <roywspencer@hotmail.com>; Travis Fisher <travis.scott.fisher@gmail.com>; Steven Koonin <steven.koonin@gmail.com>
Subject: Re: Ch 8 Extreme weather - new thread

several comments

I don't like table 12.12 in this chapter, since the chapter is about detection -- not attribution and not projections (and I detest showing extreme emissions scenario)

The general idea of this re-organization is good

I would lead with temperature extremes and then precip extremes, since the IPCC has actually detected a change in these

I will redo the hurricane one (ryan maue's figure is good but i have other suggestions)

On Sun, May 11, 2025 at 8:28 PM Ross McKittrick <ross.mckittrick@gmail.com> wrote:

Here is a suggested version that might work ...

Taking Judy's reduced collection of excerpts I put each one at the start of its section so that any contextual discussion occurs right away. To make these easier to find I pasted them from Judy's document in gray text. I added in the NCA17 heat wave chart. I also put the IPCC Table 12.12 in with an explanation that it's not strictly speaking trend detection and we did attribution in Ch 7 but it's still helpful context.

The chapter sequence is:

- 8.1 Introduction
- 8.2 IPCC Table 12.12
- 8.3 hurricanes and TCs

- 8.4 Temperature extremes
- 8.5 Extreme precip
- 8.6 Tornadoes
- 8.7 Flooding
- 8.8 Droughts
- 8.9 Wildfires
- 8.10 Summary

I took out the AI-generated summary that was in previously since it seemed overly focused on Table 12.12.

--



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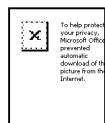
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From: Ross McKittrick [ross.mckittrick@gmail.com]
Sent: 5/12/2025 3:28:14 AM
To: Judith Curry [curry.judith@gmail.com]; John Christy [climatemanager60@gmail.com]; Roy W. Spencer [roywspencer@hotmail.com]; Travis Fisher [travis.scott.fisher@gmail.com]; Steven Koonin [steven.koonin@gmail.com]
Subject: Ch 8 Extreme weather - new thread
Attachments: 8 Extreme weather.May11.[RM].docx

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8 Extreme weather in the US and elsewhere

8.1 Introduction

Weather extremes, usually related to temperature and/or precipitation, often ~~can~~ disrupt infrastructure and therefore ~~endanger~~ human health and ~~thrivability~~ wellbeing. Indeed, the ability of any surface-dwelling species to live productively is somewhat constrained by these extremes which in essence create the bounding limits for survival. The issue is not whether extremes occur, for they are intrinsic to the chaotic climate system. Rather, it is whether there are long-term (decadal scale) changes in the frequency and/or character of extremes ("detection"), as well as the extent to which such changes ~~here is whether these extremes, and their attendant changes in potential danger~~ hazards, may ~~are~~ be changing and if so whether the change is in response ~~caused by~~ to anthropogenic emissions increases in infrared-absorbing greenhouse gases (GHGs) ("attribution"; (e.g., IPCC AR6 Seneviratne et al. 2021).

It is naïve to assume that any recent unprecedented extreme event observed recently is caused by human influences on the climate. Unfortunately, ~~that's~~ That assumption is wrong in two ways. First, climate is about the statistical properties of weather over decades, not single events. And second, there are only about 130 years of the reliable. Unfortunately, observational records that can be analyzed statistically, extend back only for the sample of time from which we are able to quantitatively analyze variations in extreme events is quite brief, about around 130 years. That brief interval does not. This period certainly does not begin to contain all of the extreme events that the climate system is able to ~~can~~ create naturally on its own. Over geologic time the climate system has generated an (essentially) infinite variety of weather patterns and extremes which ~~that~~ humans have never observed, and thus ~~do not enter our~~ are absent from the databases from which ~~used to~~ determine extreme statistics.¹ ~~are determine d~~ [see *Perils of short data records* below]. Thus, assuming that ~~a~~ For that reason, attributing climate pattern or an extreme event hitherto unprecedented in the record ~~not experienced in our lifetime~~ must therefore be the result of enhanced GHG concentrations requires the assumptions about the smallness/magnitude of that ~~natural~~ variations, are insignificant.

This is especially true for precipitation events. The hydrological literature has long noted the phenomenon of *Long Term Persistence* (LTP) in rainfall data (Hurst 1951, Cohn and Lins 2005, Markonis and Koutsoyiannis 2015). LTP has a formal mathematical definition but it can be thought of intuitively as the presence of natural variations with strong autocorrelation properties that result in cycle-like behavior on long time scales. The presence of LTP requires very-long data samples/records to obtain accurately accurate estimates of variance/variability. Analysis of, analysis of data samples that are records short relative to the LTP scale will tend to yield underestimates variability, therefore underestimated variances which in turn yields overstating the significance of apparent trends and underestimation underestimating of the likelihood of extreme events (Cohn and Lins 2005).

A good example of LTP is the eight-century long record of the annual minimum height of the Nile River observed at Roda Island in Cairo ~~shown below~~ in Figure 8.1.1. Since human influences on the global climate were negligible before the 20th century, the century-scale variability of the thirty-year average is entirely natural; Egyptians of the seventh and eight centuries would have been incorrect to assume that the worsening drought during that time was the "new normal."

Commented [A1]: Need to get a good citation for these data

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¹ For example, under the simplest statistical assumptions there is a 37 percent chance that a 100-year event is NOT present in a century-long record.

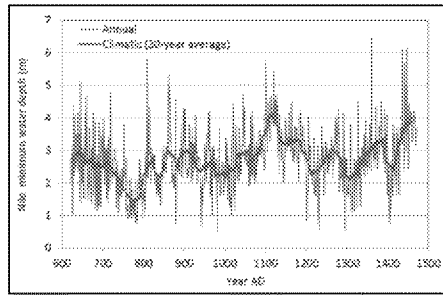


Figure 8.1.1: Nile River discharge [details, source]

With these caveats in mind we examine the evidence for changes in selected weather and climate extremes. A theme that emerges when reviewing this topic is the wide gap between public perceptions and scientific evidence. It has become routine in media discussions, government and private sector discussions and even in some academic literature to make generalized assertions that extreme weather of all types is getting worse due to GHGs and climate change. Yet expert assessments have not typically drawn such sweeping conclusions and instead have emphasized the difficulty both of identifying specific trends and establishing a causal connection with anthropogenic forcing.

In the sections to follow we cite provide excerpts from various IPCC and NCA assessment reports denoting the sources as follows:

For the benefit of readers who may not have read the relevant reports in the Appendix to this chapter we will begin provide with extended excerpts of these findings from previous IPCC and NCA assessments, then in the remainder of this chapter survey additional data relevant to US and global extreme weather trends.

8.2 Review of IPCC and NCA Findings on Extreme Weather

The sources we review will be denoted as follows:

SREX: The IPCC *Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation* (2012)

AR5: The IPCC *Fifth Assessment Report Working Group 1* (2013).

AR6: The IPCC *Sixth Assessment Report Working Group 1* (2021).

NCA17: The US *Climate Science Special Report of the Fourth National Climate Assessment* (2017) Volume I Chapter 6.

Note that in the excerpts provided *italics* are in the original whereas **boldface** emphasis is added.

8.2.1 Overview Context: IPCC Assessment of signal emergence in extreme weather types (AR6-WG1 Table 12.12)

This chapter is concerned with detection of trends. Chapter 7 looked at attribution including for extreme weather. Since there is considerable public interest in the question of whether humans are causing trends in extreme weather to get worse it is useful to begin with the summary Table 8.2.1 which reproduces the findings of AR6 Table 12.12 which indicates, for 34 major weather event and impact types, whether a signal of anthropogenic forcing has been detected in the historical record (column 1), whether such a signal is likely to emerge by 2050 under the extreme RCP8.5 scenario (column 2) and whether it is likely to emerge by 2100 under RCP8.5 forcing (column 3). It should be borne in mind that the latter two columns suffer from the deficiencies of GCMs discussed in Chapter XX. And as we discussed in Ch X7 on attribution, AR6 offers conflicting messages about attribution of extreme weather. Nevertheless, we provide this Table for reference context.

Several patterns stand out. First, detection of an anthropogenic signal is asserted with *high confidence* in only four of the 34 weather impact categories, and with *medium confidence* in a further four. The IPCC does NOT claim to have detected an anthropogenic signal in the remaining 26 categories. Of the four *high confidence* assertions, two are for changes in average temperatures (air and ocean), which are not measures of extreme weather. Further, two of the four *medium confidence* assertions are related to ocean chemistry and are also not related to extreme weather. The IPCC does NOT assert a detectable human influence on many non-temperature weather features such as wind, precipitation, flooding, and drought.

Second, columns 2 and 3 show that the IPCC expects very few anthropogenic trends to emerge within this century, even under the most extreme forcing scenario. As we discuss in Section 4.2 the RCP8.5 scenario is an implausible high-end storyline, not a “base case” or “business-as-usual” projection. Even so, most weather impacts are not expected to show an anthropogenic signal this century. Natural variability dominates patterns of extreme weather systems and simplistic assertions of trend detection are frequently undermined by regional heterogeneity and trend reversals over time.

Climate Impact Driver Type	Climate Impact Driver Category	Already Emerged in the Historical Record?	Emerging by 2050 in Most Extreme CO2 Emissions Scenario?	Emerging by 2100 in Most Extreme CO2 Emissions Scenario?
Heat & Cold	Average air temperature	YES in most regions	YES	YES
	More heat extremes	YES in most regions	YES in land regions	YES
	Fewer cold extremes	YES in a few regions	YES in many regions	YES
	Less frost	NO	NO	NO
Wet & Dry	Average Precip. (Increase or Decrease)	NO	YES (incr) YES (decr)	YES (incr) YES (decr)
	River flooding	NO	NO	NO
	Heavy precip & pluvial flood	NO	NO	YES in a few regions
	Landslide	NO	NO	NO
	Aridity	NO	NO	NO
	Hydrologic Drought	NO	NO	NO
	Agricultural & ecological drought	NO	NO	NO
	Fire weather	NO	NO	NO
Wind	Average wind speed	NO	NO	NO
	Severe wind storm	NO	NO	NO
	Tropical cyclone	NO	NO	NO
	Sand and dust storm	NO	NO	NO
Snow and Ice	Snow, glacier & ice sheet	NO	YES in a few regions	YES Arctic snow
	Permafrost	YES	YES	YES
	Lake & river ice	NO	YES	YES

	Arctic sea ice	YES	YES	YES
	Antarctic sea ice	NO	YES	YES
	Heavy snowfall and ice storm	NO	NO	NO
	Hail	NO	NO	NO
	Snow avalanche	NO	NO	NO
Coastal	Relative sea level	NO	YES	YES
	Coastal flood	NO	NO	NO
	Coastal erosion	NO	NO	NO
Open Ocean	Average ocean temperature	YES	YES	YES
	Marine heat wave	NO	NO	NO
	Ocean acidity	NO	YES	YES
	Ocean salinity	YES	YES	YES
	Dissolved oxygen	YES (Pacific & S. Ocean)	YES	YES
Other	Air pollution weather	NO	NO	NO
	Solar or IR radiation at surface	NO	NO	NO

Table 8.2.1. IPCC AR6 summary of the probable emergence of an anthropogenic signal above natural climate variability for all global or regional "climate impact drivers" (CIDs) of concern for humans and ecosystems in response to increasing atmospheric greenhouse gas concentrations (primarily CO₂). Source: Table adapted from report of Working Group I, Table 12.12). Red = high confidence; yellow = medium confidence; green = no anthropogenic signal detectable above natural variability (50% confidence).

Taking wind as an example, the IPCC claims that an anthropogenic signal has ~~NOT~~ emerged in average wind speeds, severe windstorms, tropical cyclones, or sand and dust storms, and none are expected to emerge this century even under an extreme emissions scenario. The same applies to drought and fire weather. This table alone suffices to illustrate the gap between IPCC expert assessments of extreme weather and discussions in the popular media and political arenas. As we show below the Table reflects longstanding conclusions of the IPCC and other assessment bodies. In the next few sections we will simply present without comment excerpts from past assessment reports.² In selecting these excerpts, we've focused on the highest-level summaries to avoid accusations of bias through "cherry picking".

² In these excerpts we have added **bold face** emphasis, while *italicized* emphasis on confidence terms appears in the original sources. Citations in quoted text can be found in the underlying reports but are not reproduced here.

8.2.73 Hurricanes and Tropical Cyclones

The AR6 assessed this topic as follows.

AR6: There is *low confidence* in most reported long-term (multidecadal to centennial) trends in TC frequency or intensity-based metrics due to changes in the technology used to collect the best-track data. (Chapter 11, p. 1585)

AR6: It is *likely* that the global proportion of major (Category 3–5) tropical cyclone occurrence has increased over the last four decades. . . . There is *low confidence* in long-term (multi-decadal to centennial) trends in the frequency of all-category tropical cyclones. (SPM A.3.4)

AR6: A subset of the best-track data corresponding to hurricanes that have directly impacted the United States since 1900 is considered to be reliable, and shows **no trend in the frequency of U.S. landfall events**. (Chapter 11 Summary, p. 1585)

Hurricane strength records for the North Atlantic and the Western Pacific go back to 1950 and the record does not show an increase in either total or major TCs. Figure 8.3.1 was published by Roger Pielke Jr. as an update to the Best Track data series originally presented in Weinkle et al. (2012).

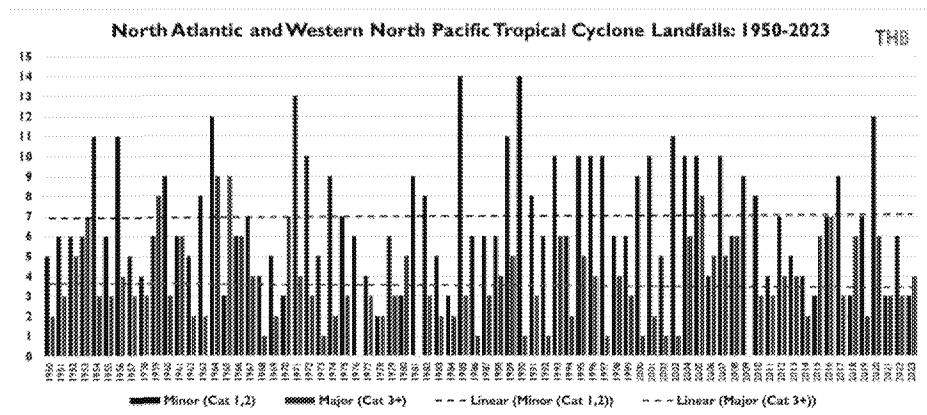


Figure 8.3.1. Tropical Cyclone Landfalls. Source: [HYPERLINK "<https://rogerpielkejr.substack.com/p/global-tropical-cyclones>"]. Weinkle et al. (2012)

Similarly, Figure 8.3.2 (Maue 2025, [HYPERLINK "<https://climatlas.com/tropical/>"]) shows that both all hurricanes and major hurricanes have not become more common since 1980, the period of rapidly growing human influences. In fact, both numbers have trended down slightly since the 1990s:

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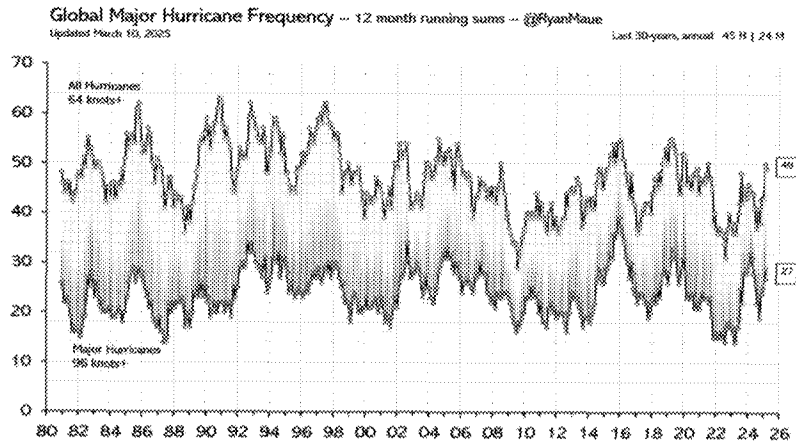


Figure 8.3.2: Global hurricane frequency. Source: Maue (2025)

A metric that combines the number, duration, and strength of TCs is the Accumulated Cyclone Energy (ACE) Index maintained at Colorado State University, shown in Figure 8.3.3. It clearly shows no long-term increase, in fact declining slightly since 1990.

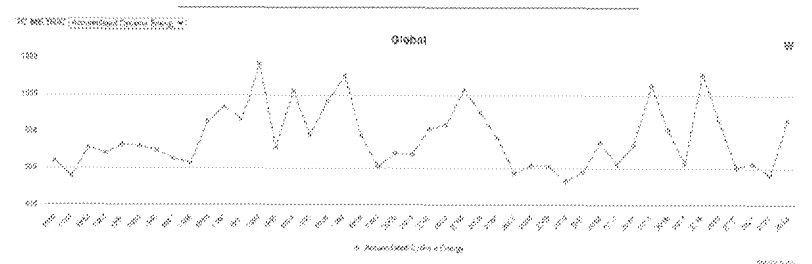


Figure 8.3.3: Global Accumulated Cyclone Energy. Source: Klotzbach (2025)

[HYPERLINK "<https://tropical.atmos.colostate.edu/Realtime/index.php?arch&loc=global>"]

Note that Tu et al. (2024) report that the Power Dissipation Index (PDI), another different measure that combines hurricane number, duration, and strength, has either remained unchanged or has declined in all global oceanic basins since the mid-1990s.

Today's global climate simulations are too coarse to project changes in TCs directly. Rather, projections are derived from finer "downscaled" simulations or proxies involving sea surface temperatures, winds, and aerosols. By those methods, a warming climate is expected to show declining hurricane formation rates. (Chand et al. 2022). Climate models also project fewer Tropical Cyclones under future global warming, and even though models project they will increase in strength, the annual averages of rainfall maxima decline (Stansfield et al. 2020).

8.3 Tornadoes SREX (p. 159):

There have been no significant trends observed in global tropical cyclone frequency records, including over the present 40-year period of satellite observations (e.g., Webster et al., 2005). Regional trends in tropical cyclone frequency have been identified in the North Atlantic, but the fidelity of these trends is debated (Holland and Webster, 2002; Landsea, 2007; Mann et al., 2007a). Different methods for estimating undercounts in the earlier part of the North Atlantic tropical cyclone record provide mixed conclusions (Chang and Guo, 2007; Mann et al., 2007b; Kunkel et al., 2008; Vecchi and Knutson, 2008). Regional trends have not been detected in other oceans (Chan and Xu, 2009; Kubota and Chan, 2009; Callaghan and Power, 2011). It thus remains uncertain whether any observed increases in tropical cyclone frequency on time scales longer than about 40 years are robust after accounting for past changes in observing capabilities (Knutson et al., 2010).

AR5 (pp. 216-17):

Current data sets indicate no significant observed trends in global tropical cyclone frequency over the past century and it remains uncertain whether any reported long-term increases in tropical cyclone frequency are robust after accounting for past changes in observing capabilities (Knutson et al., 2010). No robust trends in annual numbers of tropical storms, hurricanes and major hurricanes counts have been identified over the past 100 years in the North Atlantic basin. Measures of land-falling tropical cyclone frequency (Figure 2.34) are generally considered to be more reliable than counts of all storms which tend to be strongly influenced by those that are weak and/or short lived. Callaghan and Power (2011) find a statistically significant decrease in Eastern Australia land-falling tropical cyclones since the late 19th century although including 2010/2011 season data this trend becomes non-significant (i.e., a trend of zero lies just inside the 90% confidence interval). Significant trends are not found in other oceans on shorter time scales (Chan and Xu, 2009; Kubota and Chan, 2009; Mohapatra et al., 2011; Weinkle et al., 2012), although Grinstead et al. (2012) find a significant positive trend in eastern USA using tide gauge data from 1923–2008 as a proxy for storm surges associated with land-falling hurricanes. Differences between tropical cyclone studies highlight the challenges that still lie ahead in assessing long-term trends.

In summary, this assessment does not revise the SREX conclusion of *low confidence* that any reported long-term (centennial) increases in tropical cyclone activity are robust after accounting for past changes in observing capabilities. More recent assessments indicate that it is *unlikely* that annual numbers of tropical storms, hurricanes and major hurricanes counts have increased over the past 100 years in the North Atlantic basin. Evidence, however, is for a virtually certain increase in the frequency and intensity of the strongest tropical cyclones since the 1970s in that region.

AR6 (p. 1585)

There is *low confidence* in most reported long-term (multidecadal to centennial) trends in TC frequency or intensity-based metrics due to changes in the technology used to collect the best-track data. This should not be interpreted as implying that no physical (real) trends exist, but rather as indicating that either the quality or the temporal

length of the data is not adequate to provide robust trend detection statements, particularly in the presence of multidecadal variability.

There are previous and ongoing efforts to homogenize the best-track data (Elsner et al., 2008; Kossin et al., 2013, 2020; Choy et al., 2015; Landsea, 2015; Emanuel et al., 2018) and there is substantial literature that finds positive trends in intensity-related metrics in the best-track during the "satellite period", which is generally limited to the past ~40 years (Kang and Elsner, 2012; Kishinawa et al., 2012; Kossin et al., 2013, 2020; Mei and Xie, 2016; Zhao et al., 2018; Taeyale and Tsuboki, 2019). When best-track trends are tested using homogenized data, the intensity trends generally remain positive, but are smaller in amplitude (Kossin et al., 2013; Holland and Brayera, 2014). Kossin et al. (2020) extended the homogenized TC intensity record to the period 1979–2017 and identified significant global increases in major TC exceedance probability of about 6% per decade.² In addition to trends in TC intensity, there is evidence that TC intensification rates and the frequency of rapid intensification events have increased within the satellite era (Kishinawa et al., 2012; Balaguru et al., 2018; Bhatia et al., 2018). The increase in intensification rates is found in the best-track as well as the homogenized intensity data.

A subset of the best-track data corresponding to hurricanes that have directly impacted the United States since 1900 is considered to be reliable, and shows no trend in the frequency of U.S. landfall events (Knutson et al., 2019).

AR6: [O]bservational trends in tornadoes, hail, and lightning associated with severe convective storms are **not robustly detected** due to insufficient coverage of the long-term observations. There is *medium confidence* that the mean annual number of tornadoes in the USA has remained relatively constant. (Chapter 11, section 11.7.3, p. 1594)

As noted there is no evidence of trends in US tornadoes or extreme convective storms. Extreme precipitation will be discussed further below.

8.34 Temperature extremes

The AR6 assessment focused on the period after 1950 and reported increasing trends in heatwave frequency and intensity. The NCA17 however noted that heatwave activity in the US reached a peak in the 1930s.

²The underlined text referenced a study (Kossin et al., 2020) that later retracted a portion of its findings. Those authors assembled a data set on global TC incidence spanning 1979 to 2017 from which they claimed that the global fraction of TCs reaching major status (Cat 3–5) rose from 27% during 1979–1997 to 31% during 1998–2017 and that the increase was statistically significant. However, closer examination of their results showed a significant increase only in the North Atlantic (18% to 34%) whereas changes in all other basins (Eastern Pacific, Western Pacific, North Indian, South Indian, South Pacific) were not statistically significant. In a subsequent correction ([HYPERLINK "https://www.pnas.org/doi/10.1073/pnas.2021573117"]), Kossin et al. stated that the global probability of observing a major TC rose from 34% during 1979–1997 to 37% in the later period and that the evidence for statistical significance was now weaker. Nevertheless, the authors claimed that the correction did not affect their conclusions.

AR6: "It is *virtually certain* that hot extremes (including heatwaves) have become **more frequent** and **more intense** across most land regions since the 1950s, while cold extremes (including cold waves) have become less frequent and less severe" (SPM, A3.1)

AR6: "In North America, there is very robust evidence for a *very likely* increase in the intensity and frequency of hot extremes and decrease in the intensity and frequency of cold extremes for the whole continent, though there are substantial spatial and seasonal variations in the trends. Minimum temperatures display warming consistently across the continent, while there are more contrasting trends in the annual maximum daily temperatures in parts of the USA." (Chapter 11, p 1550)

NCA17: "Changes in warm extremes are more nuanced than changes in cold extremes. For instance, the warmest daily temperature of the year **increased** in some parts of the West over the past century, but there were **decreases** in almost all locations east of the Rocky Mountains. In fact, all eastern regions experienced a net **decrease**, most notably the Midwest (about 2.2°F [1.2°C]) and the Southeast (roughly 1.5°F [0.8°C])." (pp. 190-191)

NCA17: "Since the mid-1960s, there has been only a very slight increase in the warmest daily temperature of the year (amidst large interannual variability). Heat waves (6-day periods with a maximum temperature above the 90th percentile for 1961–1990) increased in frequency until the mid-1930s, became considerably less common through the mid-1960s, and increased in frequency again thereafter. As with warm daily temperatures, heat wave magnitude reached a **maximum in the 1930s**." (pp. 190-191)

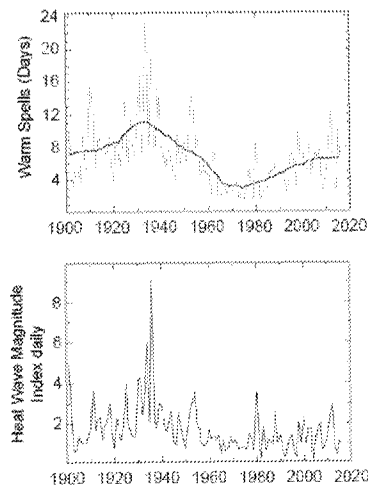


Figure 8.24.1: US Heat waves since 1900. Source: NCA17, Figure 6.4

8.24.1 Temperatures in the US are becoming less extreme

Daily maximum temperatures in the warm season (TMax, May-Sep) and daily minimum temperatures in the cold season (TMin, Dec-Mar) are available beginning in Dec 1898 (126 years). The dataset consists of 1,211 CONUS stations designated as United States Historical Climate Network

or USHCN stations (see Figure 8.34.12; Quinlan et al. 1987, Karl et al. 1990). These stations were selected by NOAA as having the fewest problematic issues with gaps, station moves and instrument changes. Where gaps still exist, nearby stations (bias-corrected) were merged so that the median volume of data available for a station is 98%. Although there are certainly errors in the dataset, with over 1,000 stations we can have relatively high confidence in any underlying signal that might be discovered.

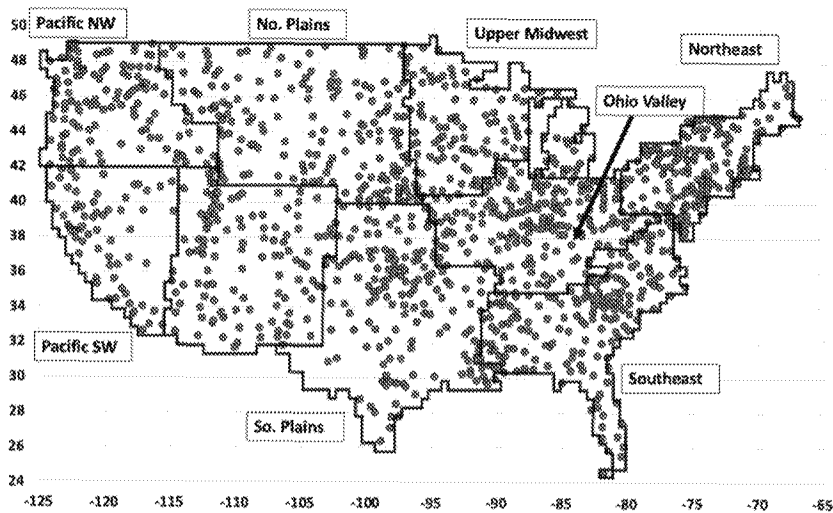


Figure 8.34.12 Locations of USHCN temperature stations. Source: USHCN.

We begin with the question of whether the occurrence of daily record high or low temperatures changed has changed since Dec 1898. Each warm-season has 153 days (1 May to 30 Sep) and each cold-season has 122 days (1 Dec to 31 Mar). For each station and day, we calculated the year in which the record highest (lowest) temperature occurred. With 126 years of observations, if there were no temperature trends over time, the expected number of records for TMax would be 1.21 ($=153/126$) per station per year and for TMin 0.96 ($=122/126$) per station per year. Figure 8.4.13.3 indicates the observed distribution in time of the occurrence of these extreme events.

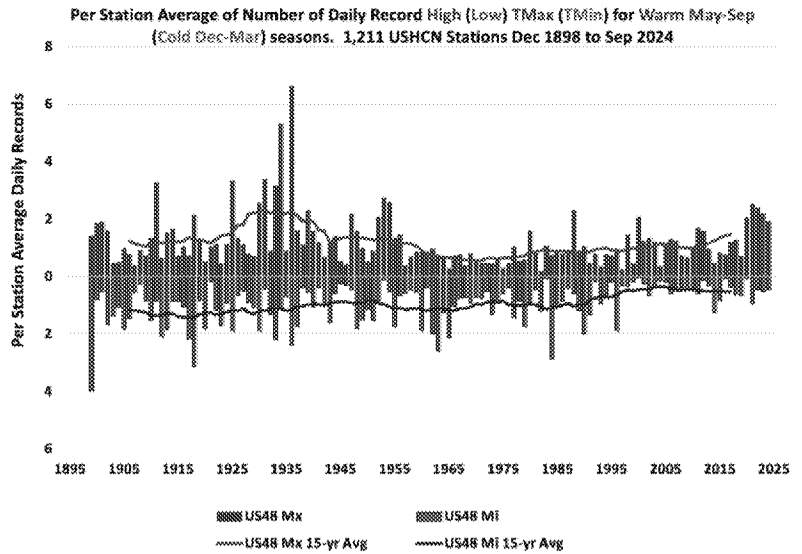


Figure 8.34.23 Number of daily record High (red) and Low (blue) for warm and cold seasons in the CONUS. The lines represent the 15-year running, centered average. Source: 1,211 USHCN stations supplemented as needed to achieve a minimum of 92% of observations in the 126-year period since Dec 1898.

The results indicate a common feature in many metrics of warm-season extremes in the CONUS - the exceptional heat of the 1920s and especially the 1930s, peaking in 1936. On a per-station average, 60% of the TMax records and 59% of the TMin records occurred in the first half of the period (1899-1961).

On the cold side, the Valentine's Day Arctic outbreak in Feb 1899 stands as the most extensive cold extreme experienced by the CONUS, with 1917 2nd. The frequency of cold records has declined, especially over the last quarter of the period in which only 13% of the extreme cold events were measured. In contrast, 25% of the extreme TMax records were achieved in the last quarter in accordance with statistical expectations. These general features have been noted in past assessments (IPCC AR5, IPCC AR6, NCA4, NCA5). Combining the two records the overall reduction in numbers of both cold and hot extremes over the past century indicates a climate less prone to extremes.

This pattern is also shown in Figure 8.34.34.3. For each station and for each year the hottest warm season and coldest cold-season temperatures were calculated and converted to anomalies relative to the station's long term warm and cold season (respectively) averages. Then the differences between these were computed by station and geographically-averaged over all stations, thus yielding an annual measure of the expected range of local extreme temperatures for each year. Figure 8.4.44.4 shows the 15-year trailing average of this measure which has clearly declined over the past century.

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**Yearly difference between hottest day in summer and coldest night in winter
Conterminous US, 15-year trailing average**

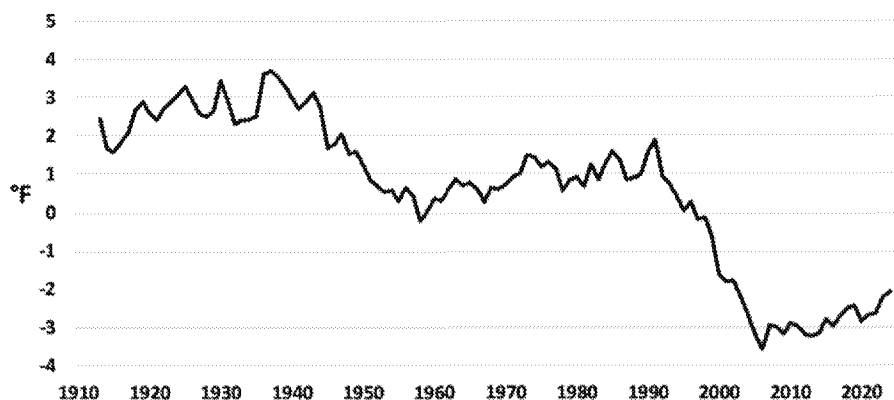


Figure 8.34.34. 15-year trailing average of the difference each year of each station's hottest warm-season TMax and coldest cold-season TMin relative to the long-term average. Source: USHCN, author calculations.

The average difference for each station between the hottest summer TMax and coldest winter TMin has declined about 5°F in the past 126 years. The decline is due mostly to warming winter TMin, but a decline in the magnitude of summer TMax is also a factor. The rise in TMin has been strongly related to the growing presence of manufactured surfaces around the weather stations over the last 100+ years (Spencer et al. 2025).

Summarizing Figures 8.4.134.23 and 8.4.23.4.4 while temperature extremes are regularly experienced in the US and attract a great deal of media attention, long term records show the US climate has become less extreme over time (milder) when measured in terms of the range between warm season maxima and cold season minima.

8.4.2.2 Exceedances of a heat threshold

Under the heading of "The Risk of Temperature Extremes is Changing", the most recent US National Climate Assessment report (NCA5) notes the increase in a threshold metric of number of days at or above 95°F, stating,

"The western US has been particularly affected by extreme heat since the 1980s ..., experiencing a larger increase in days over 95°F, as would be expected given the greater warming in that region relative to the eastern US. Several major heatwaves have affected the US since 2018, including a record-shattering event in the Pacific Northwest in 2021."

Are the occurrences of 95°F days changing? In a climate as varied as that of CONUS, threshold statistics can be misleading. A region with many stations that have near 95°F TMax average temperatures in the summer might see large swings in the metric when only small changes in average temperature occur. Elsewhere with stations that either rarely or virtually always achieve 95°F TMax temperatures, a small change will not impact the results much at all. In the past 126 years, the average CONUS station experienced 129 days exceeding 95°C per 6-yr period, but the regional values range from 278 in the Southern Plains to 9 in the Northeast. Thus, one needs to view such threshold analyses with caution.

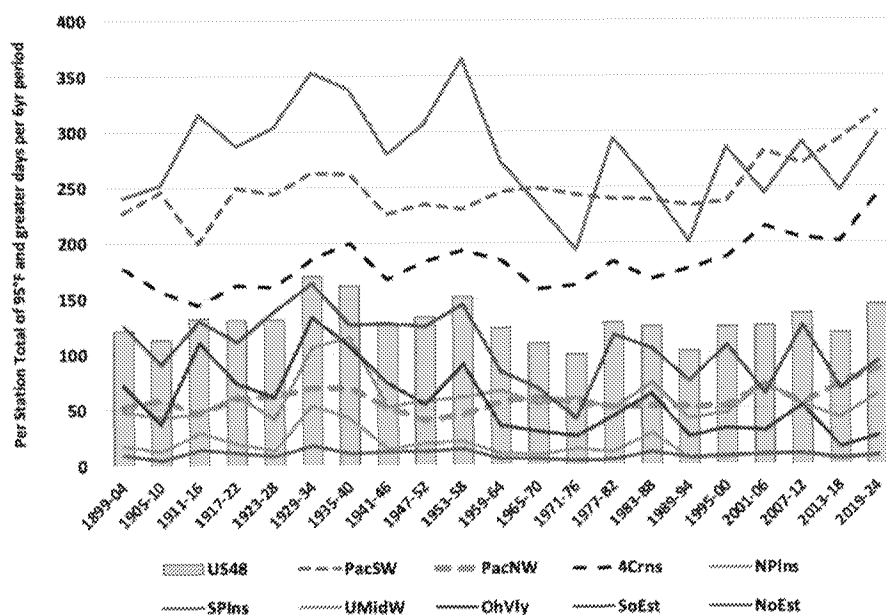


Figure 8.4.334.45. Total number of days $\geq 95^{\circ}\text{F}$ in 6-yr periods, US 48 (bars) and regions (lines). Source: USHCN, author calculations.

In Fig. 8.4.334.45 we see that only three of the nine regions, all in the West, have experienced upward trends in the number of 95°F or hotter days (dashed lines). The CONUS as a whole has not and the other six regions have experienced declines.

The Pacific NW heatwave of 2021 is referenced as of the NCA5 claim, an event we examine more closely in Section 6.4. The evidence indicates it was a "black swan" event; i.e., a single, unprecedented event in the record, not part of a pattern of increasing extreme heat. For example, the 5-day average tropospheric grid-point temperature anomaly over the Pacific NW during that event was $+10.8^{\circ}\text{C}$, the

most extreme NH grid point summer anomaly in the 46 years from over 4 million grids. In contrast the global anomaly during that time was virtually zero (+0.03 C, Mass et al. 2024).

The heading "The Risk of Temperature Extremes is Changing" suggests positive trends are now being observed in threshold temperatures on a widespread basis, but that is not evidenced in the combined CONUS results of the figures above.

8.4.434.3 Heatwaves

Heatwaves (consecutive days that exceed an extreme threshold) have a greater societal impact than a single daily record. We measure "Heatwave Days" here as the count of all days in May-Sep each year that exceed the 90th percentile and that lie within a run of at least six consecutive days. This is equivalent to the method used in NCA5 except that the reference period here is the entire record 1899-2024 while NCA5 truncated the reference period to 1961-1990, a cool time. That truncation boosts positive results (days exceeding the 90th percentile) in periods warmer than the reference period, especially starting in 1960 and moving to the present (see *Urban Influences* below).

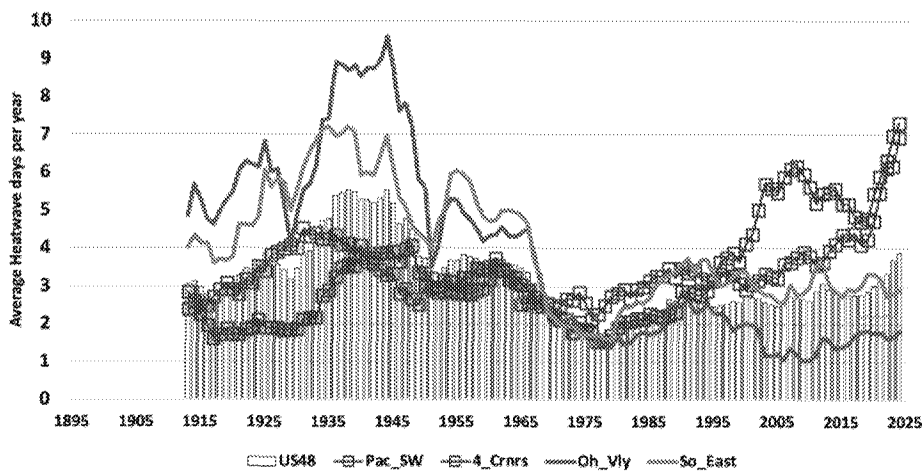


Figure 8.4.434.56 15-year trailing average of number of heatwave days per year per station in the CONUS (bars) and four regions: Pac SW (purple squares, CA, NV), 4_Crnrs (red squares, AZ, NM, UT, CO), Oh_Vly (blue, MO, IL, KY, TN, IN, OH, WV) and So_East (green, MS, AL, GA, FL, SC, NC, VA).

Figure 8.4.434.56 indicates again the excessive heat of the first half of the 20th century, primarily in the eastern two-thirds of the nation, as seen in the regional values for the Ohio Valley and the Southeast as examples. The West has seen a recent increase of heatwave days and the two regions with the highest number are shown, the Pacific Southwest and the Four-Corners (NCA5). This indicates that the background warm season circulation favored heatwaves in the eastern portions of the country in the first half of the 20th century, but in the 21st century the patterns have favored

heatwaves in the West. For CONUS as a whole, heatwaves are no more common today than they were a century ago.

Of interest here is the regional variation of this metric. The four northern regions (Pacific NW, Northern Plains, Upper Midwest, and Northeast) on average experience 15 to 27 heatwave days per 15-year period. In contrast, the five southern regions (Pacific Southwest, 4-Corners, Southern Plains, Ohio Valley and Southeast) see 37 to 54 such days, essentially twice as many. This suggests the summer circulation pattern is more prone to stationary events in the southern regions while transient systems in the northern regions are more common and thus cut short these potentially longer events.

8.24.4 Urban influences

The NCA5 directs readers to the website [HYPERLINK "https://www.globalchange.gov/indicators/heat-waves"] (USGCRP 2023) to view the number of urban heatwaves by decade from the 1960s. The figure shows a monotonic increase in each decade from 2 occurrences per year in the 1960s to 6 in the 2020s. The definition of a heatwave is an unusual but practical measure of human discomfort - a period of at least 2 consecutive days when the minimum apparent temperature (combination of temperature and humidity) exceeds the 85th percentile. Note too, the dataset is limited to the 50 largest U.S. cities.

These increasing values since 1960 presented in USGCRP (2023) are entirely reasonable, but are unrelated to GHG emissions for at least two reasons. Urbanization in these cities is a major factor in the rise of TMin relative to co-located TMax and relative to TMin at rural stations. Also, the 1960s was the coldest decade and 1970s the second coldest decade since the 1910's, so this starting date preconditions the time series to show increases. This does not dismiss the real rise in nighttime temperatures in major U. S. cities and the societal impacts associated with these changes. However, we note for a variety of reasons, that summer TMax (especially in rural areas) serves as better response variable for detecting potential changes in heatwaves influenced by changes in the background climate due, for example, to increasing GHGs (Christy et al. 2009). For the CONUS as a whole, the evidence in this section suggests GHG emissions have had little-to-no effect on heatwaves.

8.4 Tornadoes

AR6: [O]bservational trends in tornadoes, hail, and lightning associated with severe convective storms are not robustly detected due to insufficient coverage of the long-term observations. There is medium confidence that the mean annual number of tornadoes in the USA has remained relatively constant. (Chapter 4.1, section 4.1.7.3, p. 4594)

As noted there is no evidence of trends in US tornadoes or extreme convective storms. Extreme precipitation will be discussed below.

8.455 Extreme precipitation

The IPCC AR6 assessed that an increase in heavy precipitation has been observed in data starting in the 1950s.

AR6: "The frequency and intensity of heavy precipitation events have **increased** since the 1950s over most land area for which observational data are sufficient for trend analysis (high confidence)." (SPMA3.2)

AR6: "In North America, there is robust evidence that the magnitude and intensity of extreme precipitation has *very likely* **increased** since the 1950s. Both [one-day maxima] and [5-day maxima] have significantly increased in North America during 1950-2018" (Chapter 11, p.1560)

However other data sources indicate less evidence of increasing extreme precipitation when examined over a longer time scale.

Figure 8.45.1 shows that US long term data from NOAA shows an insignificantly increasing tendency toward extreme wetness (+0.001% per year)

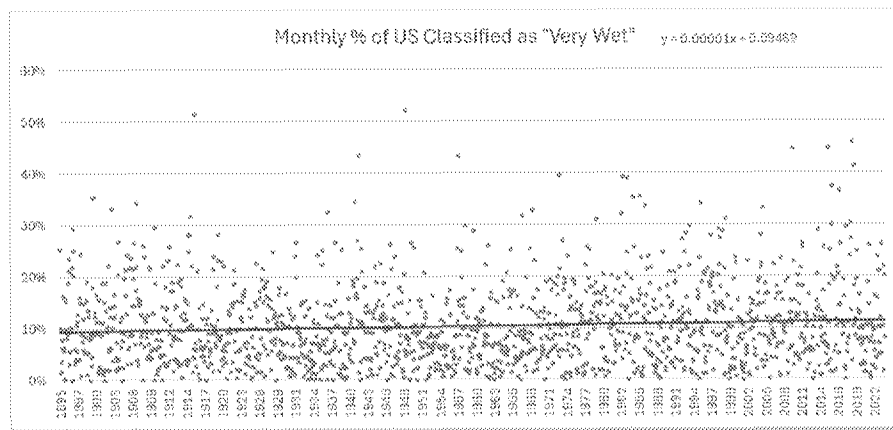
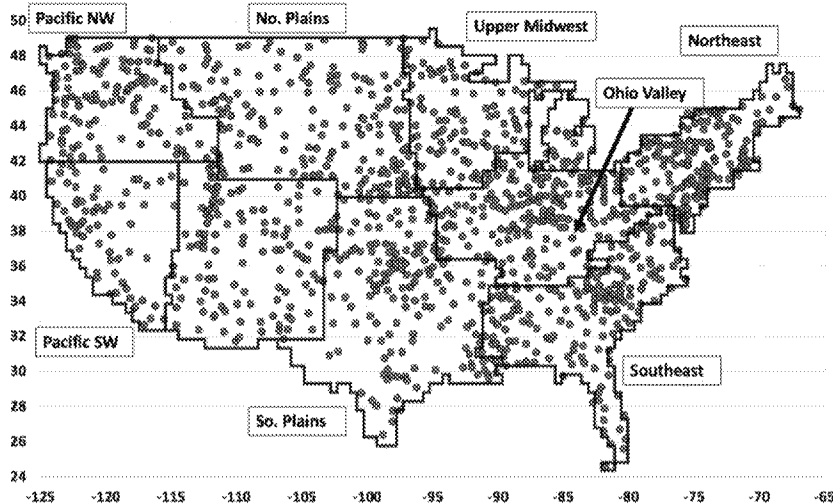


Figure 8.45.1: Long term US wetness (%). Source: NOAA [HYPERLINK "<https://www.ncei.noaa.gov/access/monitoring/uspa/wet-dry/0/>"]

Because precipitation involves a discrete phase change (water vapor to liquid), it is ~~stochastic and episodic~~ in character and requires careful statistical treatment to understand variability over long time periods (see 8.1 Introduction). The US National Climate Assessments (NCA4, NCA5) have highlighted an increase in the occurrence of the heaviest precipitation events (defined in different ways) primarily in the eastern half of the CONUS, especially the Northeast, when starting in either 1901 or 1958. Interestingly, the regional variations indicate that the largest increases in extreme events are in the Northeast and the smallest in the West, a trend counter to the changes in temperature extremes.

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McKittrick and Christy (2019) examined long-term and consistent station observations of daily precipitation to test some of these NCA claims for the Southeast and West Coast. When the time series were extended back in time (as far as 1872 in some cases) or when starting later (1978), there were no significant trends for either region.

For this report we updated these findings with similarly constructed observations from 29 stations on the Pacific Coast (1893ff from San Diego CA to Blaine WA) and -24 stations in the humid Southeast (1872ff from Austin TX to Washington DC), and also adding 21 stations in the Northeast (1888ff from Buffalo NY to Gardiner ME). The results of applying the analysis of McKittrick and Christy (2019) were as follows.

[will generate map of stations -RM]

Pacific region:

- Average precipitation trend is significant (downwards) in Astoria, insignificant elsewhere.
- The trend in rainfall variance is positive and significant in Big Sur, insignificant elsewhere.
- The trend in daily maximum precipitation is positive and significant in Aberdeen and Big Sur and negative and significant in Newport (insignificant elsewhere).
- Averaged over all stations in the region none of these three trend parameters is statistically significant.

Southeast region:

- The trend in average precipitation is positive and significant in Mobile and Quitman, insignificant elsewhere.
- The trend in rainfall variance is positive and significant in Mobile, insignificant elsewhere.
- The trend in daily maximum precipitation is positive and significant in Vicksburg and Norfolk, insignificant elsewhere.
- Averaged over all stations in the region none of these three trend parameters is statistically significant.

Northeast region:

- The trend in average precipitation is positive and significant in 9 of 21 locations and in the region averaged overall.
- The trend in rainfall variance is positive and significant in Portland, Albany and Buffalo, insignificant elsewhere.
- The trend in daily maximum precipitation is positive and significant in Portland and Gardiner, insignificant elsewhere.
- Averaged over all stations in the region the trend parameters for variance and maximum precipitation are not statistically significant.

Pacific Coast heavy rainfall events

The Pacific Coast receives considerable precipitation from Atmospheric River (AR) events which often last more than a day or two (e.g., Gershunov et al. 2017, Pan et al. 2024). The worst-known such event in recent history was the ArkStorm that occurred between December 1861 and January 1862, which dumped nearly 10 feet of rain in parts of California and submerged the entire Central Valley for weeks under as much as 15 feet of water (Brewer 1930, Null and Hulbert 2007). Paleoclimate research has found six megastorms more severe than 1861–1862 in California during the last 1800 years, occurring at intervals of 300 years or so (Porter et al. 2011).

SIDEBAR: Perils of short data records

San Francisco provides a good case study of the limitation of using short historical samples to characterize natural variability of extreme events. Suppose we use a 130-year sample of daily San Francisco precipitation from 1895 to 2024 and we look for 3-day, 5-day, 14-day and 30-day rainfall records. The results are as shown in Table 8.2.

<u>Event</u>	<u>Record (inches)</u>	<u>Year</u>
<u>3-day</u>	<u>6.94</u>	<u>2023</u>
<u>5-day</u>	<u>8.55</u>	<u>2023</u>
<u>14-day</u>	<u>12.62</u>	<u>2023</u>
<u>30-day</u>	<u>18.93</u>	<u>1998</u>

Table 8.2: Extreme rainfall records, San Francisco, 1895-2024.

The records all cluster in the more recent data. 2023 appears to be an exceptional year and since it is near the end of the sample it might suggest that the climate has shifted into a more hazardous state, perhaps as a result of human influences.

But the picture is very different if we use a sample that begins 45 years earlier, in 1850. Table 8.3 shows that the record-setting events then all happened in the 1860s. Furthermore 2023 is now not even in 2nd place but falls to 3rd or 4th. Also, comparing the records of the two charts the extreme precipitation events in 1862 and 1867 involved considerably more rainfall than the 1998 and 2023 events, with 14- and 30-day totals about 50 percent higher.

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<u>Event</u>	<u>Record (inches)</u>	<u>Year</u>	<u>Rank of 130-yr extreme</u>
<u>3-day</u>	<u>8.85</u>	<u>1867</u>	<u>3</u>
<u>5-day</u>	<u>9.80</u>	<u>1867</u>	<u>3</u>
<u>14-day</u>	<u>19.05</u>	<u>1862</u>	<u>4</u>

30-day	28.25	1862	2
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Table 8.3: Extreme rainfall records, San Francisco, 1850-2024.

The range of natural variability is made even more remarkable when paleoclimate evidence is examined. Porter et al. (2011) discovered that in the past 1,800 years at least six megastorms were more intense than the devastating 1861-62 ArkStorm that struck the region. Evidently such extreme events have impacted the region about every 300 years, though not since 1895.

This example illustrates the limitations of using relatively short climate periods (~130 years) to assess the character and range of natural variability in general and of extreme events in particular. Accurate representation of the full range of natural variability is necessary for any attribution analyses (see 6.4). Infrastructure planners, emergency management institutions and attribution scientists would understand the significant mischaracterization of the magnitude of a future extreme if based only on the last 130 years. In this case, a single time-sample of 130 years provides an underestimation of the extreme value by up to 50% determined when adding only 45 more years of observations. Compared to millennial-scale paleoclimate evidence, an even greater underestimation would occur. An important lesson is that the climate can deliver great surprises on its own, even without human influences.

We examine occurrences of 5-day deluges as follows. In a 130-year span there are 26 5-year intervals. At each location we computed the 5-day precipitation totals throughout the year and selected the 26 highest values. A single year may have more than one of the 26 heaviest. Each of those can be thought of as 1-in-5yr events. If there are no trends in precipitation then the total number of these events across all stations should be evenly spread out over the years. In Fig. 8.4-55.1 we show the distribution in time of these events. The deluges associated with the massive 1997-98 El Niño event are readily apparent. While erratic, as is typical of these types of precipitation metrics, there is no indication of a tendency to become more frequent over time.

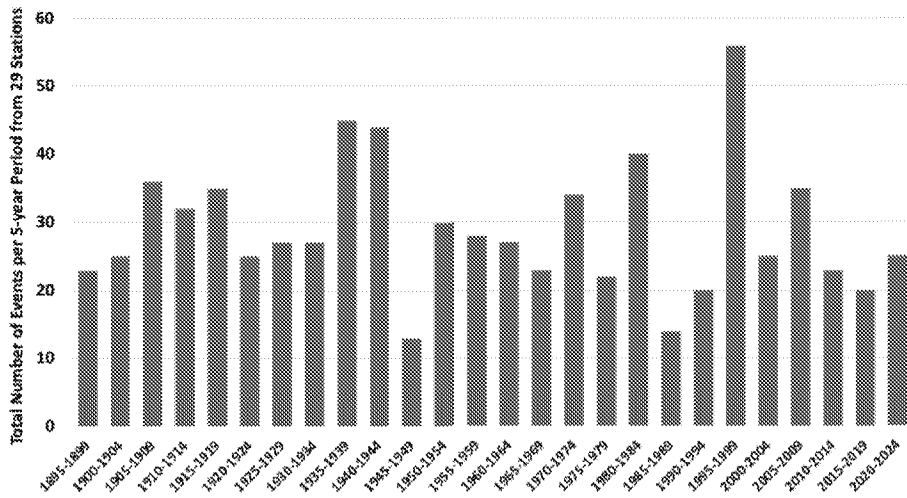


Figure 8.5.24.5. The time distribution by 5-year periods of the 26 heaviest occurrences for each station (i.e., nominal 1-in-5 year event).

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Southeast heavy rainfall events

The temporal pattern of 5-day totals of the 1-in-5yr heavy events in the humid Southeast (Figure 8.4.45.2) is generally unremarkable, though a cluster of higher values appears in 1995 to 2019. The increase in those years is due largely to the 4 northeastern-most stations of Wilmington NC, Weldon NC, Washington DC, and Norfolk VA. This confirms the pattern indicated in NCA4 and NCA5 of a tendency for an increasing frequency of heavy events, due to a temporal clustering of tropical storms from eastern NC to Maine discussed below. Otherwise, the remaining 20 stations show an unremarkable temporal distribution of heavy events.

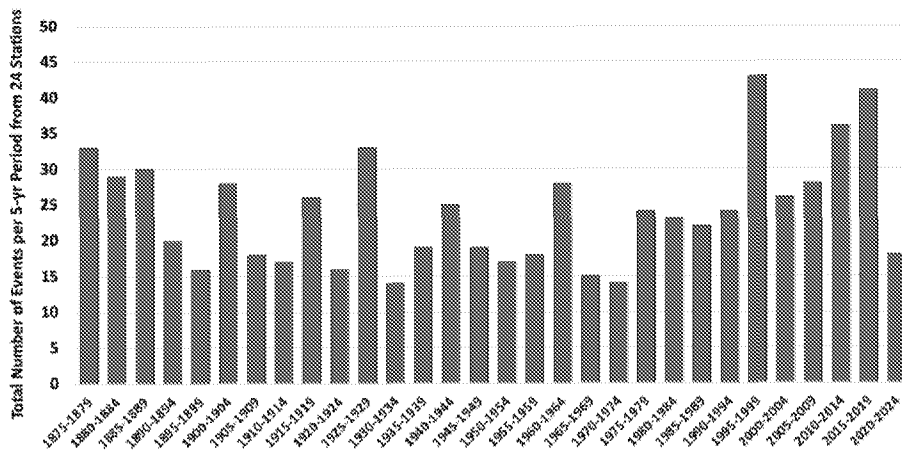


Figure 8.4-65.3. As above but for the 30 heaviest 1-in-5yr events for 24 stations in the humid Southeast from Austin TX to Washington DC in 5-year bins for 1875-2024.

Northwest heavy rainfall events

Fig. 8.4-75.3 shows the 27 (1-in-5yr) heaviest 3-day events for the last 135 years in 21 stations in the Northeast (including Montreal Canada). We use 3-day totals here as this produced the largest variations in time. In this region, 72% of the events occur during June to October and are dominated by tropical incursions of hurricanes, tropical storms or tropical storms that transition to extratropical systems. According to NCA4 and NCA5 this region experienced the largest increases in extreme events, so it shall be examined more closely.

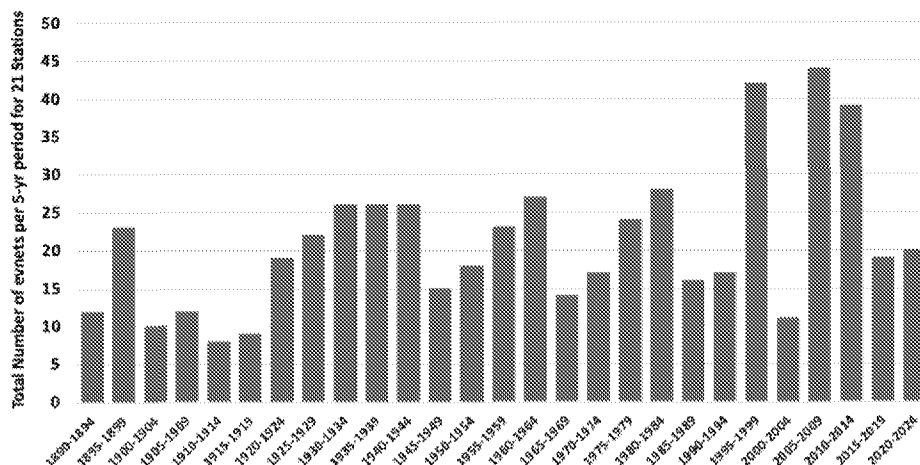


Figure 8.4-75.4. Time distribution of the heaviest 27 (1-in-5yr) heaviest 3-day precipitation events for 21 stations from NY to ME, including Montreal.

Howarth et al. (2019) report differences in the Northeast between two 18-year periods: 1979-96 and 1997-2014 (a similar region as in Fig. 8.16 that includes PA and NJ) of various precipitation extremes. One metric which indicated a dramatic increase (317%) was found for 24-hr events > 6 inches. This high increase is due to the very small numbers of such events of which there were only 6 in the first period and 25 in the second as reported for 58 stations. This high percentage increase is due to the very small numbers of the events; only 6 in the first period and 25 in the second. Most of the stations did not record such an event suggesting these erratic, episodic events over brief, 18-yr periods, need scrutiny by additional statistical methods.

Using the information in Fig. 8.4-75.4 over the same years as Howarth et al. we find a 51% increase in the frequency of heavy events between the two periods. One can see in Fig. 8.16 that it was unfortunate that Howarth et al. ended in 2014 prior to a return to the long-term average of such events.

A feature of Howarth et al. is the use of single day totals which is questionable because extreme events are often spread across the time-of-observation boundary. Thus stations measuring at 0700 LT versus those at Midnight will have differing results for a particular event which would then have major impacts on counting these events. We use the 3-day totals in Fig. 8.4-75.4 to be sure to capture the extent of these extreme downpours. In any case, we can confirm that the period 1997 to 2014 experienced a cluster of heavier events as Howarth et al. have documented.

Howarth's most remarkable claim (317% increase in 6" days) is potentially misleading because it is a threshold statistic (see Section 8.4.2-8.3.2 above) and a ratio of small numbers over a short period. The result is not representative of *relative* extreme events for the whole region since the majority of stations never experienced a 6" total. Figure 8.4-65.5.4 above determines the same number of events for each station (27 heaviest events) whose heaviest values ranged from 4.4" to 12.5" and their 27th heaviest values ranged from 3.3" to 5.0". This analysis thus allows each station to

be equally represented. In other words, if there is a region-wide increase in heavy events, it should be seen in the sum of all stations. Note too that the period of record here is 135 years vs. 36 years of Howarth et al. Except for three 5-year periods between 1995 and 2014 there is nothing statistically remarkable about the results in Fig. 8.4.7.

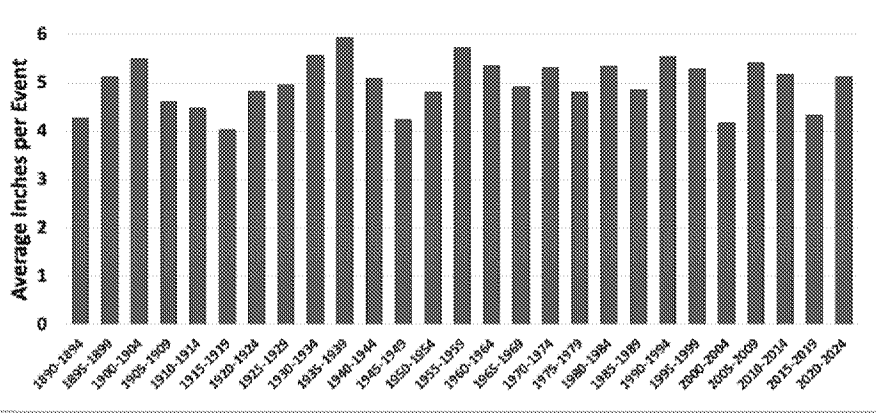


Figure 8.4.85.5. Average amount of precipitation falling in the 1-in-5yr events for the NE stations.

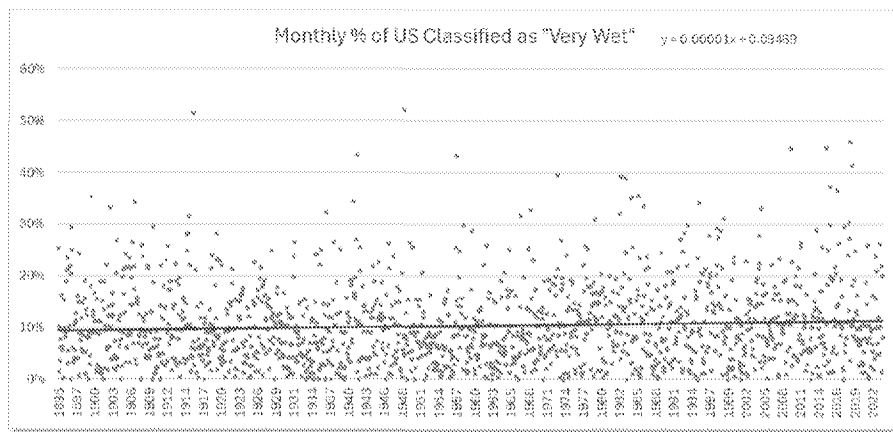
An interesting aspect of Northeast precipitation is that there has been no change in the amount of precipitation per heaviest event, as shown in Fig. 8.4.85.5. The trend is only $+0.02"/\text{decade}$. The highest amount, 1935-39, includes the Great New England Hurricane of 1938, one of the rare major (Category 3 or higher) hurricanes to strike the region. The results in Figs. 8.4.65.4 and 8.4.75.5 suggest that though there was an uptick in the number of events during the period 1995 to 2014, the events, individually, are not becoming more intense.

long et al. (2024) document the increase of tropical influences on precipitation events in the Northeast since 1959 and concluded, "The autumn extreme precipitation trend over the Northeast US is primarily attributed to tropical cyclone-related events since the 1990s." The question then becomes, was the temporal clustering of tropical systems in 1997-2014 which affected the Northeast a response to increasing GHGs? long et al. examined CMIP-6 model output which suggests that there will be fewer such systems in the 21st century but that the intensity of the rainfall events might increase. This conjecture is not seen in Fig. 8.17 where the amount-per-event has remained steady over the 135-year period.

For substantial urban areas there is some evidence to indicate the heaviest rainfall events may be redistributed due to the impact urban infrastructure has on the local weather (e.g., Pielke Sr. et al. 2011, Zhang et al. 2018, Yang et al. 2024). Yang et al. state, "Cities that experience compact development tend to witness larger increases in extreme rainfall frequency over downtown than their rural surroundings, while the anomalies in extreme rainfall frequency diminish for cities with

dispersed development.” While this is an important insight to consider, the effect on the specific stations used in this analysis is unknown, or at least not detectable in Fig. 8.17.

In summary, the evidence from the historical record of extreme precipitation events in the CONUS is generally not consistent from region to region so that inferences regarding trends and their projections are wrought with significant uncertainty. In most regions and perhaps all, it is our opinion that the very nature of the erratic and episodic character of extreme precipitation events renders the discovery of statistically significant changes, including a relationship to CO2 concentrations, a result yet to be achieved (McKittrick and Christy 2019).



8.6 Tornadoes

AR6: [O]bservational trends in tornadoes, hail, and lightning associated with severe convective storms are **not robustly detected** due to insufficient coverage of the long-term observations. There is *medium confidence* that the mean annual number of tornadoes in the USA has remained relatively constant. (Chapter 11, section 11.7.3, p. 1594)

As noted there is no evidence of trends in US tornadoes or extreme convective storms.

Figure 8.3.84.1: Long-term US wetness (%). Source: NOAA. [HYPERLINK "<https://www.ncei.noaa.gov/access/monitoring/uspa/wet-dry/0>"]

8.2.2.7 Flooding

Changes in floods were assessed as follows:

AR6: "The SREX assessed *low confidence* for observed changes in the magnitude or frequency of floods at the global scale. This assessment was confirmed by the AR5 report. The SRI 5 found increases in flood frequency and extreme streamflow in some regions, but decreases in other regions. . . [H]ydrological literature on observed flood changes is heterogeneous, focusing at regional and sub-regional basin scales, making it difficult to synthesise at the global and sometimes regional scales." (Chapter 11.5)

AR6: "[T]he seasonality of floods has changed in cold regions where snowmelt dominates the flow regime in response to warming (*high confidence*). Confidence about peak flow trends over past decades on the global scale is *low*." (Chapter 11.5)

NCA17: "Trends in extreme high values of streamflow are **mixed** across the United States. Analysis of 200 U.S. stream gauges indicates areas of both increasing and decreasing flooding magnitude but does not provide robust evidence that these trends are attributable to human influences" (pp. 240-241)

The absence of detectable US-wide trends in flooding is consistent with the findings in the previous section of absence of coherent changes in extreme precipitation.

SREX (p. 176)

In the United States and Canada during the 20th century and in the early 21st century, **there is no compelling evidence for climate-driven changes in the magnitude or frequency of floods.**

AR5 (p. 214)

AR4 WGI Chapter 3 (Trenberth et al., 2007) did not assess changes in floods but AR4 WGII concluded that **there was not a general global trend in the incidence of floods** (Kundzewicz et al., 2007). SREX went further to suggest that there was low agreement and thus *low confidence* at the global scale regarding changes in the magnitude or frequency of floods or even the sign of changes.

AR5 WGII assesses floods in regional detail accounting for the fact that trends in floods are strongly influenced by changes in river management (see also Section 2.5.2). Although the most evident flood trends appear to be in northern high latitudes, where observed warming trends have been largest in some regions no evidence of a trend in extreme flooding has been found, for example, over Russia based on daily river discharge (Shklomanov et al., 2007). Other studies for Europe (Hannafor and Marsh, 2009; Renard et al., 2009; Petrow and Merz, 2009; Stahl et al., 2010) and Asia (Jiang et al., 2008; Delgado et al., 2010) show evidence for upward, downward or no trend in the magnitude and frequency of floods, so that there is

currently no clear and widespread evidence for observed changes in flooding except for the earlier spring flow in snow-dominated regions (Seneviratne et al., 2012). In summary, there continues to be a lack of evidence and thus low confidence regarding the sign of trend in the magnitude and/or frequency of floods on a global scale.

AR6 (Ch 11 p. 1568)

The SREX (Seneviratne et al., 2012) assessed low confidence for observed changes in the magnitude or frequency of floods at the global scale. This assessment was confirmed by the AR5 report (Hartmann et al., 2013). The SR15 (Hoegh-Guldberg et al., 2018) found increases in flood frequency and extreme streamflow in some regions, but decreases in other regions. While the number of studies on flood trends has increased since the AR5 report, and there were also new analyses after the release of SR15 (Berghuijs et al., 2017; Blöschl et al., 2019; Gudmundsson et al., 2019), hydrological literature on observed flood changes is heterogeneous, focusing at regional and sub-regional basin scales, making it difficult to synthesise at the global and sometimes regional scales.

In summary, the seasonality of floods has changed in cold regions where snowmelt dominates the flow regime in response to warming (high confidence). Confidence about peak flow trends over past decades on the global scale is low, but there are regions experiencing increases, including parts of Asia, southern South America, the northeast USA, northwestern Europe, and the Amazon, and regions experiencing decreases, including parts of the Mediterranean, Australia, Africa, and the southwestern USA.

US NCA17 pp. 240-41:

"The IPCC AR5 did not attribute changes in flooding to anthropogenic influence nor report detectable changes in flooding magnitude, duration, or frequency. Trends in extreme high values of streamflow are mixed across the United States. Analysis of 200 U.S. stream gauges indicates areas of both increasing and decreasing flooding magnitude but does not provide robust evidence that these trends are attributable to human influences."

The complex mix of processes complicates the formal attribution of observed flooding trends to anthropogenic climate change and suggests that additional scientific rigor is needed in flood attribution studies. As noted above, precipitation increases have been found to strongly influence changes in flood statistics. However, in U.S. regions, no formal attribution of precipitation changes to anthropogenic forcing has been made so far, so indirect attribution of flooding changes is not possible. Hence, no formal attribution of observed flooding changes to anthropogenic forcing has been claimed."

8.2.3 Heatwaves

AR5 (p. 212 WG1)

Table 2.13 shows that there has been a likely increasing trend in the frequency of heatwaves since the middle of the 20th century in Europe and Australia and across much of Asia where there are sufficient data. However, confidence on a global scale is medium owing to lack of studies over Africa and South America but also in part owing to differences in trends depending on how heatwaves are defined (Perkins et al., 2012). Using monthly means as a proxy for heatwaves, Coumou et al. (2013) and Hansen et al. (2012) indicate that record-breaking temperatures in recent decades substantially exceed what would be expected by chance but caution is required when making inferences between these studies and those that

deal with multi-day events and/ or use more complex definitions for heatwave events. There is also evidence in some regions that periods prior to the 1950s had more heatwaves (e.g., over the USA, the decade of the 1930s stands out and is also associated with extreme drought conditions (Peterson et al., 2013) whereas conversely in other regions heatwave trends may have been underestimated owing to poor quality and/or consistency of data (e.g., Della-Marta et al. (2007a) over Western Europe; Kuglitsch et al. (2009, 2010) over the Mediterranean). Recent available studies also suggest that the number of cold spells has reduced significantly since the 1950s (Donat et al., 2013a, 2013c).

In summary, new analyses continue to support the AR4 and SREX conclusions that since about 1950 it is very likely that the numbers of cold days and nights have decreased and the numbers of warm days and nights have increased overall on the global scale, that is, for land areas with sufficient data. It is likely that such changes have also occurred across most of North America, Europe, Asia and Australia.

NCA17 (pp. 190-191)

Changes in warm extremes are more nuanced than changes in cold extremes. For instance, the warmest daily temperature of the year increased in some parts of the West over the past century (Figure 6.3), but there were decreases in almost all locations east of the Rocky Mountains. In fact, all eastern regions experienced a net decrease (Table 6.2), most notably the Midwest (about 2.2°F [1.2°C]) and the Southeast (roughly 1.5°F [0.8°C]). The decreases in the eastern half of [the] Nation, particularly in the Great Plains, are mainly tied to the unprecedented summer heat of the 1930s Dust Bowl era, which was exacerbated by land surface feedbacks driven by springtime precipitation deficits and land mismanagement. However, anthropogenic aerosol forcing may also have reduced summer temperatures in the Northeast and Southeast from the early 1950s to the mid-1970s, and agricultural intensification may have suppressed the hottest extremes in the Midwest.

Since the mid-1960s, there has been only a very slight increase in the warmest daily temperature of the year (amidst large interannual variability). Heat waves (6-day periods with a maximum temperature above the 90th percentile for 1961–1990) increased in frequency until the mid-1930s, became considerably less common through the mid-1960s, and increased in frequency again thereafter (Figure 6.4). As with warm daily temperatures, heat wave magnitude reached a maximum in the 1930s.

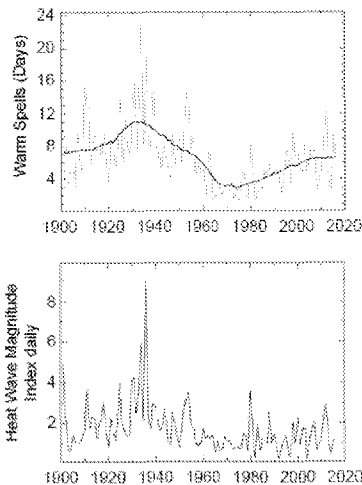


Figure 8.2.1: US Heat waves since 1900. Source: NCA17 Figure 6.4

AR6 (p. 1550)

In North America (Table 11.19), there is very robust evidence for a *very likely* increase in the intensity and frequency of hot extremes and decrease in the intensity and frequency of cold extremes for the whole continent, though there are substantial spatial and seasonal variations in the trends. Minimum temperatures display warming consistently across the continent, while there are more contrasting trends in the annual maximum daily temperatures in parts of the USA (Figure 11.9; Lee et al., 2014; van Oldenborgh et al., 2019; Dunn et al., 2020).

8.2.4 Extreme snowfall events

Note: extreme snowfall events in the US northeast are assessed in relation to winter Extratropical Cyclone (ETC) activity.

AR6 Ch 11 p. 1593

There is high confidence that snowfall associated with winter ETCs will decrease in the future, because increases in tropospheric temperatures lead to a lower proportion of precipitation falling as snow (O’Gorman, 2014; Rhoades et al., 2018; Zarzycki, 2018). However, there is medium confidence that extreme snowfall events associated with winter ETCs will change little in regions where snowfall will be supported in the future (O’Gorman, 2014; Zarzycki, 2018).

8.2.5 Extreme precipitation

SREX (p. 142)

Recent studies have updated the assessment of the AR4, with more regional results now available (Table 3-2). Overall, this additional evidence confirms that **more locations and studies show an increase than a decrease in extreme precipitation, but that there are also wide regional and seasonal variations**, and trends in many regions are not statistically significant (Table 3-2). Based on station data from Canada, the United States, and Mexico, Peterson et al. (2008a) reported that heavy precipitation has been increasing over 1950-2004, as well as the average amount of precipitation falling on days with precipitation.

AR5 (pp. 313-14)

In summary, further analyses continue to support the AR4 and SREX conclusions that **it is likely that since 1951 there have been statistically significant increases in the number of heavy precipitation events (e.g., above the 95th percentile) in more regions than there have been statistically significant decreases, but there are strong regional and subregional variations in the trends**. In particular, many regions present statistically non-significant or negative trends, and, where seasonal changes have been assessed, there are also variations between seasons (e.g., more consistent trends in winter than in summer in Europe). The overall most consistent trends towards heavier precipitation events are found in central North America (very likely increase) but assessment for Europe shows likely increases in more regions than decreases.

AR6 (p. 1560)

In North America, there is robust evidence that the magnitude and intensity of extreme precipitation has *very likely* increased since the 1950s. Both [one-day maximal] and [5-day maximal] have significantly increased in North America during 1950-2018 (Sun et al., 2020, also Figure 11.13). There is, however, regional diversity. In Canada, there is a lack of detectable trends in observed annual maximum daily (or shorter duration) precipitation (Shephard et al., 2014; Mekis et al., 2015; Vincent et al., 2018).

NCA17 pp. 213-14:

Detectability of trends (compared to internal variability) for a number of precipitation metrics over the continental United States has been examined; **however, trends identified for the U.S. regions have not been clearly attributed to anthropogenic forcing**. One study concluded that increasing precipitation trends in some north-central U.S. regions and the extreme annual anomalies there in 2013 were at least partly attributable to the combination of anthropogenic and natural forcing. **Based on current evidence, it is concluded that detectable but not attributable increases in mean precipitation have occurred over parts of the central United States**. Formal detection-attribution studies indicate a human contribution to extreme precipitation increases over the continental United States, but confidence is low based on those studies alone due to the short observational period, high natural variability, and model uncertainty.

In summary, based on available studies, it is concluded that for the continental United States there is *high confidence* in the detection of extreme precipitation increases, while there is *low confidence* in attributing the extreme precipitation changes purely to anthropogenic forcing.

8.2.6 Tornadoes and severe convective storms

Severe convective storms are convective systems that are associated with extreme phenomena such as tornadoes, hail, heavy precipitation (rain or snow), strong winds, and lightning.

The assessment of changes in severe convective storms in SREX (Chapter 3, Seneviratne et al., 2012) and AR5 (Chapter 12, Collins et al., 2013) is limited and focused mainly on tornadoes and hail storms. The SREX assessed that **there is low confidence in observed trends in tornadoes and hail** because of data inhomogeneities and inadequacies in monitoring systems. Subsequent literature assessed in the Climate Science Special Report (Kossin et al., 2017) led to the assessment of the observed tornado activity over the 2000s in the USA, with a decrease in the number of days per year with tornadoes and an increase in the number of tornadoes on these days (*medium confidence*). However, **there is low confidence in past trends for hail and severe thunderstorm winds**. Climate models consistently project environmental changes that would support an increase in the frequency and intensity of severe thunderstorms that combine tornadoes, hail, and winds (*high confidence*), but there is *low confidence* in the details of the projected increase.

In summary, because the definition of severe convective storms varies depending on the literature and the region, it is not straightforward to make a synthesizing view of observed trends in severe convective storms in different regions. In particular, **observational trends in tornadoes, hail, and lightning associated with severe convective storms are not robustly detected** due to insufficient coverage of the long-term observations. There is *medium confidence* that the mean annual number of tornadoes in the USA has remained relatively constant, but their variability of occurrence has increased since the 1970s, particularly over the 2000s, with a decrease in the number of days per year and an increase in the number of tornadoes on these days (*high confidence*). Detected tornadoes have also increased in Europe, but the trend depends on the density of observations.

In summary, it is extremely difficult to detect and attribute changes in severe convective storms. There is limited evidence that extreme precipitation associated with severe convective storms has increased in some cases.

9.2.7 Hurricanes and Tropical Cyclones

SREX (p. 159):

There have been no significant trends observed in global tropical cyclone frequency records, including over the present 40-year period of satellite observations (e.g., Webster et al., 2005). Regional trends in tropical cyclone frequency have been identified in the North Atlantic, but the fidelity of these trends is debated (Holland and Webster, 2007; London, 2007; Mann et al., 2007a). Different methods for estimating undercounts in the earlier part of the North Atlantic tropical cyclone record provide mixed conclusions (Chang and Guo, 2007; Mann et al., 2007b; Kunkel et al., 2008; Vecchi and Knutson, 2008). Regional trends have not been detected in other oceans (Chan and Xu, 2009; Kubota and Chan, 2009; Callaghan and Power, 2011). It thus remains uncertain whether any observed increases in tropical cyclone frequency on time scales longer than about 40 years are robust after accounting for past changes in observing capabilities (Knutson et al., 2010).

AR5 (pp. 216–17):

Current data sets indicate no significant observed trends in global tropical cyclone frequency over the past century and it remains uncertain whether any reported long-term increases in tropical cyclone frequency are robust after accounting for past changes in observing capabilities (Knutson et al., 2010). No robust trends in annual numbers of tropical storms, hurricanes and major hurricanes counts have been identified over the past 100 years in the North Atlantic basin. Measures of land-falling tropical cyclone frequency (Figure 2.34) are generally considered to be more reliable than counts of all storms which tend to be strongly influenced by those that are weak and/or short-lived. Callaghan and Power (2011) find a statistically significant decrease in Eastern Australia land-falling tropical cyclones since the late 19th century although including 2010/2011 season data this trend becomes non-significant (i.e., a trend of zero lies just inside the 90% confidence interval). Significant trends are not found in other oceans on shorter time scales (Chen and Xu, 2009; Kubota and Chan, 2009; Mohapatra et al., 2011; Weinkle et al., 2012) although Grinstead et al. (2013) find a significant positive trend in eastern USA using tide gauge data from 1923–2006 as a proxy for storm surges associated with land-falling hurricanes. Differences between tropical cyclone studies highlight the challenges that still lie ahead in assessing long-term trends.

In summary, this assessment does not revise the SREX conclusion of low confidence that any reported long-term (centennial) increases in tropical cyclone activity are robust after accounting for past changes in observing capabilities. More recent assessments indicate that it is unlikely that annual numbers of tropical storms, hurricanes and major hurricanes counts have increased over the past 100 years in the North Atlantic basin. Evidence, however, is for a virtually certain increase in the frequency and intensity of the strongest tropical cyclones since the 1970s in that region.

AR6 (p.1585)

There is low confidence in most reported long-term (multidecadal to centennial) trends in TC frequency or intensity-based metrics due to changes in the technology used to collect the best-track data. This should not be interpreted as implying that no physical (real) trends exist, but rather as indicating that either the quality or the temporal length of the data is not adequate to provide robust trend detection statements, particularly in the presence of multidecadal variability.

There are previous and ongoing efforts to homogenize the best-track data (Elsner et al., 2008; Kossin et al., 2013, 2020; Choy et al., 2015; Landsea, 2015; Emanuel et al., 2018) and there is substantial literature that finds positive trends in intensity-related metrics in the best-track during the “satellite period”, which is generally limited to the past 40 years (Hong and Elsner, 2012; Kishitani et al., 2012; Kossin et al., 2013, 2020; Mei and Xie, 2016; Zhao et al., 2018; Tawale and Tauboldt, 2019). When best-track trends are tested using homogenized data, the intensity trends generally remain positive but are smaller in amplitude (Kossin et al., 2013; Holland and Bruyere, 2014). Kossin et al. (2020) extended the homogenized TC intensity record to the period 1970–2017 and identified significant global increases in major TC exceedance probability of about 6% per decade. In

⁴The underlined text referenced a study (Kossin et al. 2020) that later retracted a portion of its findings. Those authors assembled a data set on global TC incidence spanning 1979 to 2017 from which they claimed that the global fraction of TCs reaching major status (Cat3–5) rose from 2.7% during 1979–1997 to 3.1% during 1999–2017 and that the increase was statistically significant. However, closer examination of their results showed a significant increase only in the North Atlantic (18% to 34%) whereas changes in all other basins (Eastern

~~addition to trends in TC intensity, there is evidence that TC intensification rates and the frequency of rapid intensification events have increased within the satellite era (Kishtawal et al. 2012; Balaguru et al. 2018; Bhatia et al. 2018). The increase in intensification rates is found in the best tracks as well as the homogenized intensity data.~~

~~A subset of the best track data corresponding to hurricanes that have directly impacted the United States since 1900 is considered to be reliable, and shows no trend in the frequency of U.S. landfall events (Knutson et al. 2019).~~

8.2.868 Droughts

Assessments of drought trends were as follows.

AR6: "Few AR6 regions show observed increases in meteorological drought" (Section 11.9, p. 1575).

AR6: "Increasing trends in agricultural and ecological droughts have been observed on all continents (*medium confidence*), but decreases only in one AR6 region (*medium confidence*). Increasing trends in hydrological droughts have been observed in a few AR6 regions." (Chapter 11 Summary)

NCA17: "As a consequence of this increased precipitation, drought statistics over the entire CONUS have declined." (p. 233)

NCA17: "Recent droughts and associated heat waves have reached record intensity in some regions of the United States; however, by geographical scale and duration, the Dust Bowl era of the 1930s remains the benchmark drought and extreme heat event in the historical record (*very high confidence*)." (p. 231)

SREX: "From a paleoclimate perspective, recent droughts are **not unprecedented**, with severe 'megadroughts' reported in the paleoclimatic record for Europe, North America, and Australia." (p. 170)

US NCA17 REPORT (Ch. 8, Wehner et al. 2017)

p. 231:

~~Recent droughts and associated heat waves have reached record intensity in some regions of the United States; however, by geographical scale and duration, the Dust Bowl era of the 1930s remains the benchmark drought and extreme heat event in the historical record (*very high confidence*). While by some measures drought has decreased over much of the continental United States in association with long-term increases in precipitation, neither the precipitation increases nor inferred drought decreases have been confidently attributed to anthropogenic forcing.~~

~~Pacific, Western Pacific, North Indian, South Indian, South Pacific) were not statistically significant. In a subsequent correction [HYPERLINK "https://www.pnas.org/doi/10.1073/pnas.2021573117"], Kossin et al. stated that the global probability of observing a major TC rose from 34% during 1979-1997 to 37% in the later period and that the evidence for statistical significance was now weaker. Nevertheless, the authors claimed that the correction did not affect their conclusions.~~

The human effect on recent major U.S. droughts is complicated. Little evidence is found for a human influence on observed precipitation deficits, but much evidence is found for a human influence on surface soil moisture deficits due to increased evapotranspiration caused by higher temperatures. (High confidence)

p. 233:

Drought is, of course, directly connected to seasonal precipitation totals. Figure 7.1 shows detectable observed recent changes in seasonal precipitation. In fact, the increases in observed summer and fall precipitation are at odds with the projections in Figure 7.5. As a consequence of this increased precipitation, drought statistics over the entire CONUS have declined.

SREX (p. 170)

From a paleoclimate perspective recent droughts are not unprecedented, with severe 'megadroughts' reported in the paleoclimatic record for Europe, North America, and Australia (Jansen et al., 2007). Recent studies extend this observation to African and Indian droughts (Sinha et al., 2007; Shanahan et al., 2009); much more severe and longer droughts occurred in the past centuries with widespread ecological, political, and socioeconomic consequences. Overall, these studies confirm that in the last millennium several extreme droughts have occurred (Breda and Badeau, 2008; Kallis, 2008; Büntgen et al., 2010).

In North America, there is medium confidence that there has been an overall slight tendency toward less dryness (wetting trend with more soil moisture and runoff; Table 3-2), although analyses for some subregions also indicate tendencies toward increasing dryness. This assessment is based on several lines of evidence, including simulations with different hydrological models as well as PDSI and CDD estimates (Alexander et al., 2006; Andreadis and Lettenmaier, 2006; van der Schrier et al., 2006a; Kunkel et al., 2008; Sheffield and Wood, 2008a; Dai, 2011).

The most severe droughts in the 20th century have occurred in the 1930s and 1950s, where the 1930s Dust Bowl was most intense and the 1950s drought most persistent (Andreadis et al., 2005) in the United States, while in Mexico the 1950s and late 1990s were the driest periods. Recent regional trends toward more severe drought conditions were identified over southern and western Canada, Alaska, and Mexico, with subregional exceptions (Dai, 2011).

SREX (p. 172)

Overall, though new studies have furthered the understanding of the mechanisms leading to drought, there is still relatively limited evidence to provide an attribution of observed changes, in particular given the issues associated with the availability of observational data (Section 3.2.1) and the definition and computation of drought indicators (Box 3-3). This latter point was mostly identified in post-AR4 studies (Box 3-3). Moreover, regions where consistent increases in drought are identified (see 'Observed Changes') are only partly consistent with those where projections indicate an enhancement of drought conditions in coming decades (see next paragraphs). We thus assess that there is medium confidence (see also Section 3.1.5) that anthropogenic influence has contributed to some changes in the drought patterns observed in the second half of the 20th century, based on its attributed impact on precipitation and temperature changes (though temperature can only

be indirectly related to drought trends; see Box 3-3). However **there is low confidence in the attribution of changes in droughts at the level of individual regions.**

AR5 (pp. 214-215)

Based on evidence since AR4, SREX concluded that there were not enough direct observations of dryness to suggest high confidence in observed trends globally, although there was *medium confidence* that since the 1950s some regions of the world have experienced more intense and longer droughts. The differences between AR4 and SREX are due primarily to analyses post-AR4, differences in how both assessments considered drought and updated IPCC uncertainty guidance.

Because drought is a complex variable and can at best be incompletely represented by commonly used drought indices, discrepancies in the interpretation of changes can result. For example, Sheffield and Wood (2008) found decreasing trends in the duration, intensity and severity of drought globally. Conversely, Dai (2011a,b) found a general global increase in drought, although with substantial regional variation and individual events dominating trend signatures in some regions (e.g., the 1970s prolonged Sahel drought and the 1930s drought in the USA and Canadian Prairies). Studies subsequent to these continue to provide somewhat different conclusions on trends in global droughts and/or dryness since the middle of the 20th century (Sheffield et al., 2012; Dai, 2013; Donat et al., 2013c; van der Schrier et al., 2013).

In summary, the current assessment concludes that there is not enough evidence at present to suggest more than low confidence in a global-scale observed trend in drought or dryness (lack of rainfall) since the middle of the 20th century, owing to lack of direct observations, geographical inconsistencies in the trends, and dependencies of inferred trends on the index choice. Based on updated studies, AR4 conclusions regarding global increasing trends in drought since the 1970s were probably overstated. However, it is likely that the frequency and intensity of drought has increased in the Mediterranean and West Africa and decreased in central North America and north-west Australia since 1950.

AR6 (Drought, Observed trends, Section 11.6.2, pp. 1573-75)

p. 1573

Strong precipitation deficits have been recorded in recent decades in the Amazon (2005-2010), south-western China (2009-2010), south-western North America (2011-2014), Australia (1997-2009), California (2014), the middle East (2012-2016), Chile (2010-2015), the Great Horn of Africa (2011), among others (van Dijk et al., 2013; Mann and Gleick, 2015; Rowell et al., 2015; Marengo and Espinoza, 2016; Dai and Zhao, 2017; Garreaud et al., 2017, 2020; Marengo et al., 2017; Brito et al., 2018; Cook et al., 2018). **Global studies generally show no significant trends in SPI time series (Orlowsky and Seneviratne, 2013; Spinoni et al., 2014), and in derived drought frequency and severity data (Spinoni et al., 2019), with very few regional exceptions (Section 11.9 and Figure 11.17).**

p. 1574

For AR6 regions, several studies suggest an increase in the frequency and areal extent of soil moisture deficits, with examples in East Asia (Cheng et al., 2015; Y. Qin et al., 2015; Jia et al., 2018), Western and Central Europe (Trnka et al., 2015b), and the Mediterranean (Hanel et al., 2018; Moravec et al., 2019; Markonis et al., 2021). **Nonetheless, some analyses also show no long-term trends in soil drying in some AR6 regions – for example, in Eastern**

North America (Park Williams et al., 2017) and Central North America (Seager et al., 2019), as well as in North Eastern Africa (Kew et al., 2021).

There is evidence based on streamflow records of increased hydrological droughts in East Asia (D. Zhang et al., 2018) and southern Africa (Gudmundsson et al., 2019). In areas of Western and Central Europe and Northern Europe, there is no evidence of changes in the severity of hydrological droughts since 1950 based on flow reconstructions (Caillouet et al., 2017; Barker et al., 2019) and observations (Vicente-Serrano et al., 2012). In North America, depending on the methods, datasets and study periods, there are differences between studies that suggest an increase (Shukla et al., 2015; Udall and Overpeck, 2017) versus a decrease in hydrological drought frequency (Mo and Lettenmaier, 2018), but in general there is strong spatial variability (Poshtiri and Pal, 2016). Streamflow observation reference networks of near-natural catchments have also been used to isolate the effect of climate trends on hydrological drought trends in a few regions, but these show limited trends in Northern Europe and Western and Central Europe (Stahl et al., 2010; Bard et al., 2015; Harrigan et al., 2018), North America (Dudley et al., 2020) and most of Australia, with the exception of Eastern and Southern Australia (X.S. Zhang et al., 2016).

p. 1575

Few AR6 regions show observed increases in meteorological drought (Section 11.9), mostly in Africa and South America (NES: high confidence; WAF, CAF, ESAF, SAM, SWS, SSA, SAS: medium confidence); a few others show a decrease (WSB, ESB, NAU, CAU, NEU, CNA: medium confidence). There are stronger signals indicating observed increases in agricultural and ecological drought (Section 11.9), which highlights the role of increased [evapotranspiration], driven by increased [Atmospheric Evaporative Demand], for these trends (Sections 11.6.2.3, 11.6.2.5). Past increases in agricultural and ecological droughts are found on all continents and several regions (WAF, CAF, WSAF, ESAF, WCA, ECA, EAS, CAU, MED, WCE, NES: medium confidence), while decreases are found only in one AR6 region (NAU: medium confidence). The more limited availability of datasets makes it more difficult to assess historical trends in hydrological drought at regional scale (Section 11.9). Increasing (MED: high confidence; WAF, EAS, SAU: medium confidence) and decreasing (NEU, SES: medium confidence) trends in hydrological droughts have only been observed in a few regions.

AR6 on Attribution (p. 1577)

There are only two AR6 regions in which there is at least medium confidence that human-induced climate change has contributed to changes in meteorological droughts (Section 11.9). In South-western South America (SSW), there is medium confidence that human-induced climate change has contributed to an increase in meteorological droughts (Beisier et al., 2016; Garreaud et al., 2020), while in Northern Europe (NEU), there is medium confidence that it has contributed to a decrease in meteorological droughts (Gudmundsson and Seneviratne, 2016) (Section 11.9). In other AR6 regions, there is inconclusive evidence in the attribution of long-term trends, but a human contribution to single meteorological events or subregional trends has been identified in some instances. In North America, the human influence on precipitation deficits is complex (Wehner et al., 2017), with low confidence in the attribution of long-term changes in meteorological drought in AR6 regions.

As shown in Figure 8.3-968.1 US long term data (NOAA) shows an insignificantly declining tendency toward extreme dryness (-0.001% per year)

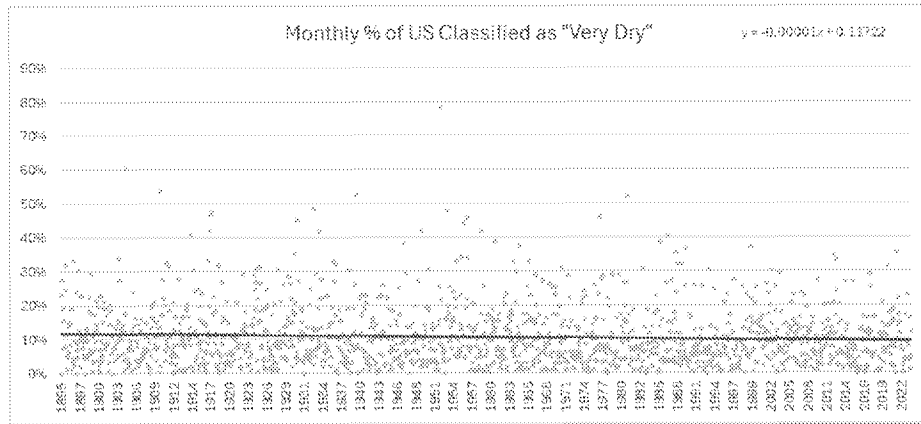


Figure 8.3-968.1: US dryness (%) 1895—2023. Source: NOAA [HYPERLINK "<https://www.ncei.noaa.gov/access/monitoring/uspa/wet-dry/0>"]

Kogan et al. (2020) examines a 38-year high-resolution satellite-based drought measure and concludes that global drought has not intensified and is not connected to climate change: "it is possible to state firmly that global and main grain countries' drought area and intensity trends have not been following global climate warmings since 1980's."

8.32 Extreme weather trends at global and continental indicators of scale extreme weather trends

8.32.1 Tropical Cyclones (TCs)

Hurricane strength records for the North Atlantic and the Western Pacific go back to 1950 and the record does not show an increase in either total or major TCs. Figure 8.3.1 was published by Roger Pielke Jr. as an update to the Best Track data series originally presented in Weinkle et al. (2012).

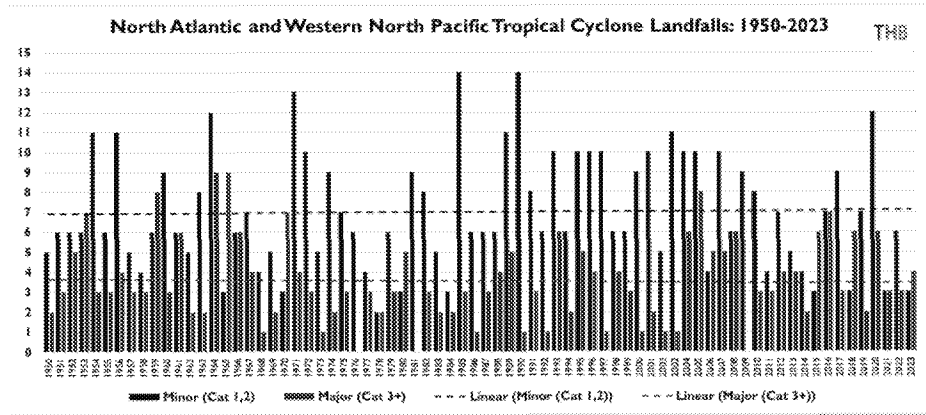


Figure 8.3.1. Tropical Cyclone Landfalls. Source: [HYPERLINK "https://rogerpielkejr.substack.com/p/global-tropical-cyclones"], Weinkle et al. (2012)

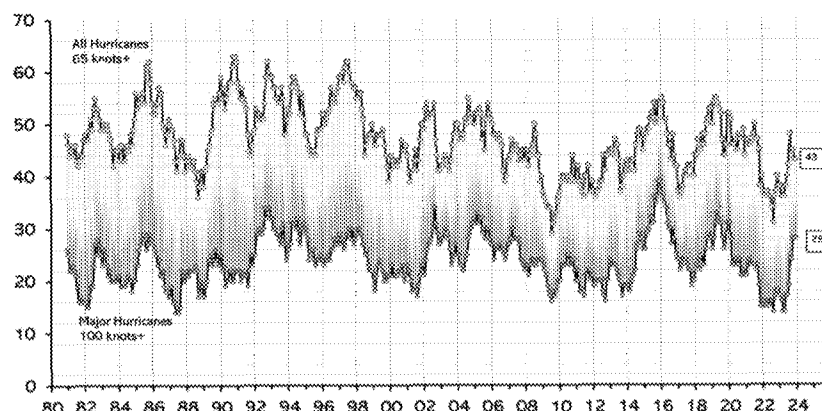
Similarly, [After 1980, as shown in Figure 8.3.2, Maue 2025, [HYPERLINK "https://climatlas.com/tropical/"]], shows that, which reproduces data from the Climate Atlas of Dr. Ryan Maue both neither all hurricanes and the total number of hurricanes nor the frequency of major ones hurricanes have not become more common since 1980, the period of rapidly growing human influences. In fact, indeed both numbers have trended down slightly since the 1990s:

Commented [A9]: Cite the Climate Atlas of Dr. Ryan Maue

Global Major Hurricane Frequency – 12 month running sums – @RyanMaue

Updated December 31, 2023

Last 30-years: 45.7 H | 24.4 M



Global Major Hurricane Frequency – 12 month running sums – @RyanMaue

Updated March 10, 2025

Last 30-years, annual: 45 H | 24 M



Figure 8.3.2: Global hurricane frequency. Source: Maue (2024/2025)

A metric that combines the number, duration, and frequency strength of TCs is the Accumulated Cyclone Energy (or ACE) Index maintained at Colorado State University, shown in Figure 8.3.3. As is clear, it is also not clearly shows no long-term increase, in fact declining slightly and since 1990 has declined slightly.

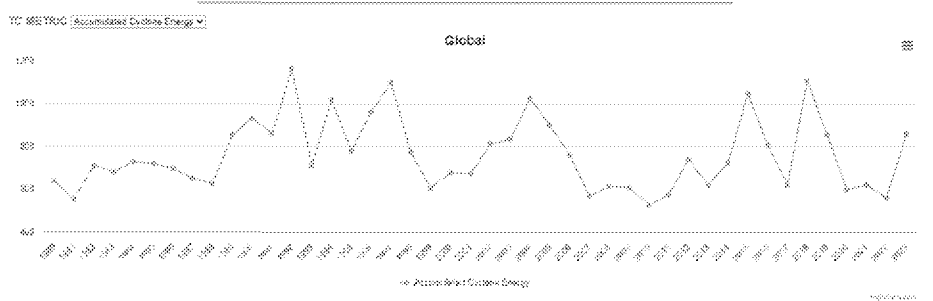


Figure 8.3.3: Global Accumulated Cyclone Energy. Source: Klotzbach (2025)
[HYPERLINK "<https://tropical.atmos.colostate.edu/Realtime/index.php?arch&loc=global>"]

Note that Tu et al. (2024) report that the Power Dissipation Index (PDI), another different measure of the destructiveness of hurricanes that combines hurricane number, duration, and strength, has either remained unchanged or has declined in all global oceanic basins since the mid-1990s. As is clear, it is also not increasing and since 1990 has declined slightly.

Today's global climate simulations are too coarse to project changes in TCs directly. Rather, projections are derived from finer "downscaled" simulations or proxies involving sea surface temperatures, winds, and aerosols. By those methods, a warming climate is expected to show climate models project declining hurricane formation rates in a warming climate (Chand et al. 2022). Climate models also project fewer Tropical Cyclones under future global warming, and even though models project they will increase in strength, the annual averages of rainfall maxima decline (Stansfield et al. 2020). Note that Tu et al. (2024) report that the Power Dissipation Index (PDI), a measure of the destructiveness of hurricanes, has either remained unchanged or has declined in all global oceanic basins since the mid-1990s.

8.23.279 Wildfires

The IPCC has not provided an assessment of wildfires.

As shown in Figures 8.3.479.1 and 8.3.5 global wildfire activity as measured by European Space Agency peaked over a decade ago and shows a downward trend since this century.

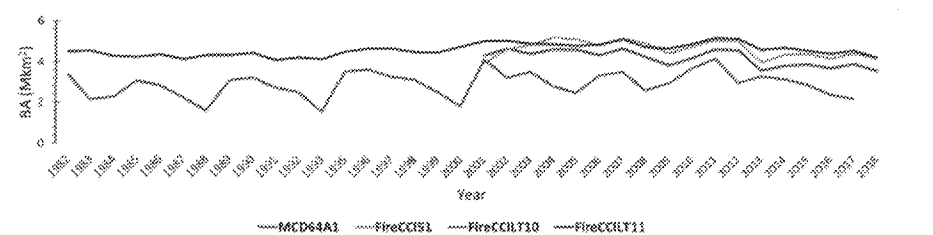


Figure 8.3.4: Global wildfire 1982-2018. Source: Copied from Oton et al. (2021). Note: the different coloured lines represent different data products based on satellites and algorithms used.

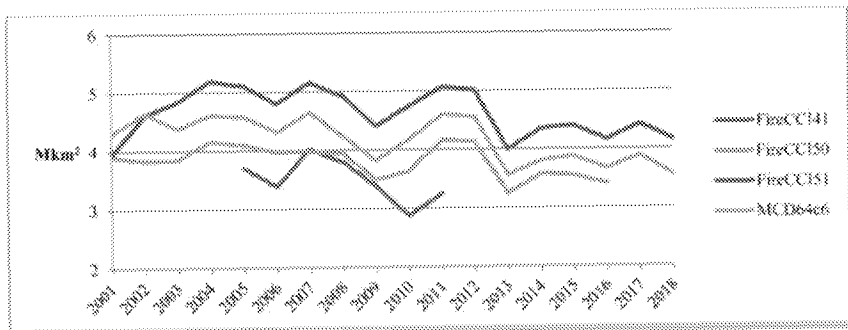


Figure 8.3.579.1: Global wildfire 2001-2018. Source: Copied from Lizundia-Loiola et al. (2021). Note: the different coloured lines represent different data products based on satellites and algorithms used

US data from the National Interagency Fire Centre (NIFC) from 1926 to 2023 are shown in Figure 8.3.6.29.2.

Commented [A9]: I thought the trends were due to declining fire in the Amazon masking any climate-related trend?

Commented [A10R9]: "global area burned appears to have overall declined over past decades, and there is increasing evidence that there is less fire in the global landscape today than centuries ago." Doerr and Santin, Proc Royal Society 2016

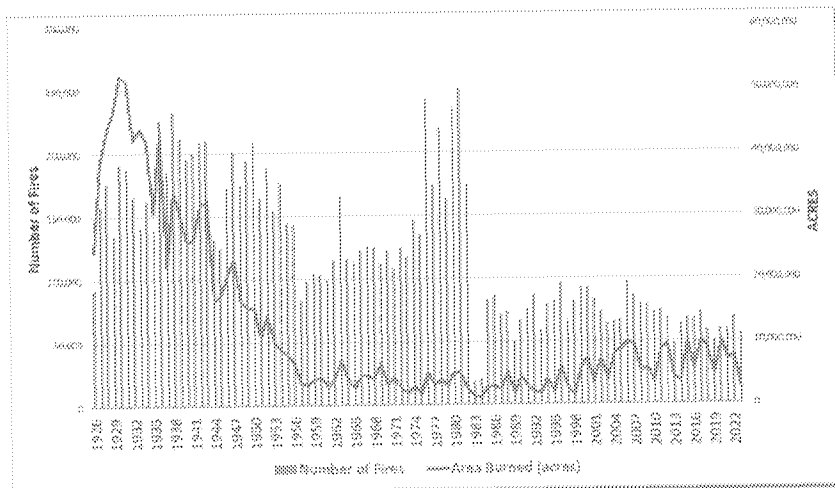


Figure 8.3-679.2: US wildfires 1926 to 2023. Source: National InterAgency Fire Centre data Pre-2017 (archived)

[<file:///C:/Users/Porter%20Hill/Dropbox/Brucehaven/Projects/DoE/Ross%20drafts/Pr>]
e-

2017):%20https:\\web.archive.org\\web\\20200212033452\\https:\\www.nifc.gov\\fireInfo\\fireInfo_stats_totalFires.html"]. 2018-2023: [HYPERLINK "https://www.nifc.gov/fire-information/statistics/wildfires"]

Note the NIFC has removed the pre-1960 data from its current website. They claim it is because measurement methods changed after 1960. This explanation seems inadequate since agencies blend temperature and extreme weather data series in other contexts when measurement systems changed. In this case if anything the measurement of wildfires has improved since the early 20th century so any bias will be towards understating early wildfire counts. Nonetheless just focusing on the post-1985 interval the number of fires is not increasing. The area burned did increase but only until about 2007.

It is difficult to establish a natural baseline for wildfire activity because of active fire suppression activity since 1900. Paleoclimatic evidence indicates, however, that past wildfire activity was much higher than at present. Marlon et al. (2012) used sedimentary charcoal layers to reconstruct fire history of western US for the past 1400 years. They also fit a model to predict expected fire activity as a function of climatic conditions. The results are summarized in Figure 8.3.79.3 below (from Figure 2 in their paper).

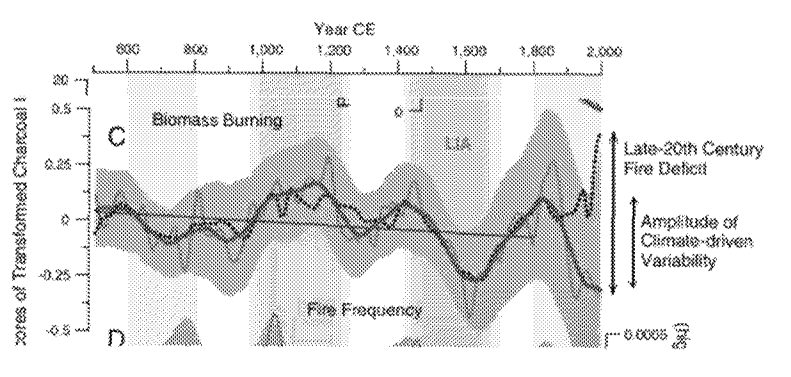


Figure 8.3.79.3 Fire frequency and fire deficit in the US. Source: Copied from Marlon et al. (2012)

In their figure the red line shows the smoothed charcoal record and the black dotted line shows the predicted charcoal record based on the statistical model. The gap at the end implies there has been a growing wildfire deficit over the 20th century. In other words, however much fire was observed in the 20th century it was less than what would have been observed in previous centuries based on the climatic conditions. Parks et al. (2025) likewise find that despite the recent increase in wildfire burn area in North America, a significant wildfire deficit remains relative to historical wildfire regimes there remains a significant wildfire deficit.

8.23.3 Precipitation

~~Figure 8.2.8 shows that US long-term data from NOAA shows an insignificantly increasing tendency toward extreme wetness (-0.001% per year)~~

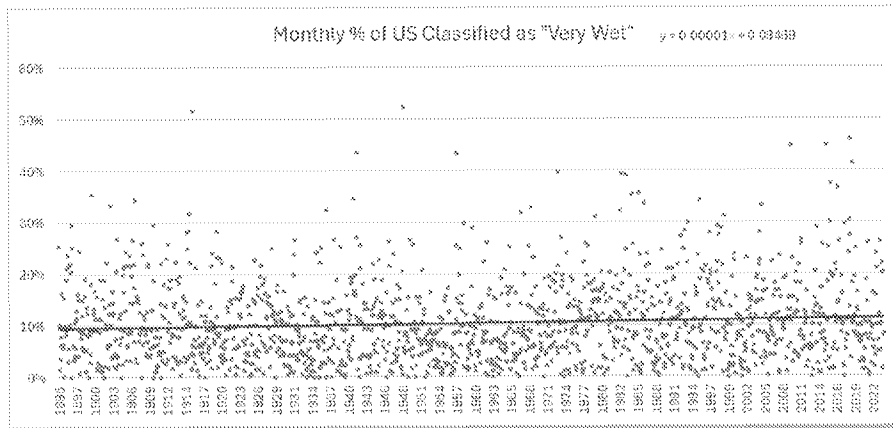


Figure 8.3.8: Long-term US wetness (%). Source: NOAA [HYPERLINK "<https://www.ncei.noaa.gov/access/monitoring/uspa/wet-dry/0/>"]

Precipitation will be discussed further in the review of CONUS data below.

8.23.4 Drought

As shown in Figure 8.3.9 US long-term data (NOAA) shows an insignificantly declining tendency toward extreme dryness (-0.001% per year)

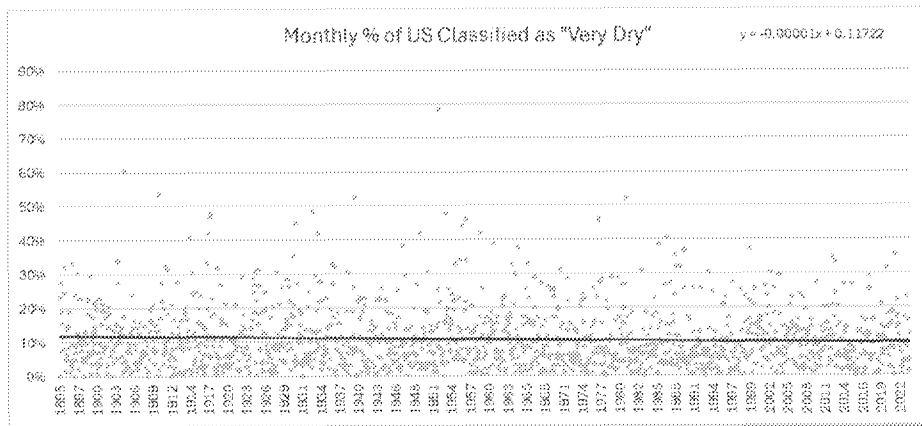


Figure 8.3.9: US dryness (%). 1895-2022. Source: NOAA [HYPERLINK "<https://www.ncei.noaa.gov/access/monitoring/uspa/wet-dry/0/>"]

Kogan et al. (2020) examines a 38-year high-resolution satellite-based drought measure and concludes that global drought has not intensified and is not connected to climate change. "It is possible to state firmly that global and main grain countries' drought area and intensity trends have not been following global climate warming since 1990's."

8.3.4 Analysis of Temperature and precipitation extremes in the Conterminous Contiguous US (CONUS) data on temperature and precipitation extremes

8.3.4.1 CONUS daily temperatures are becoming less extreme

Daily maximum temperatures in the warm season (TMax, May-Sep) and daily minimum temperatures in the cold season (TMin, Dec-Mar) are available beginning in Dec 1898 (126 years). The dataset consists of 1,211 CONUS stations designated as United States Historical Climate Network or USHCN stations (Quinlan et al. 1987, Karl et al. 1990). These stations were selected by NOAA as having the fewest problematic issues with gaps, station moves and instrument changes. Where gaps still exist, nearby stations (bias-corrected) were merged so that the median volume of data available for a station is 98%. Although there are certainly errors certainly reside in the dataset, with over 1,000 stations we can have relatively high confidence in any underlying signal we that might be discovered can be characterized by relatively high confidence.

We begin with the question of whether the occurrence of daily record high or low temperatures changed has changed since Dec 1898. Each warm season has 153 days (1-May to 30-Sep) and each cold season has 122 days (1-Dec to 31-Mar). For each station and day, we calculated the year in which the record highest (lowest) temperature occurred. With 126 years of observations, if there were no temperature trends over time, the expected number of records for TMax would be 1.21 ($=153/126$) per station per year and for TMin 0.96 ($=122/126$) per station per year. Figure 8.4.110 indicates the observed distribution in time of the occurrence of these extreme events.

Commented [A11]: Again, I think we need a map of where the stations are; something like this one:
[HYPERLINK
"https://www.researchgate.net/publication/258660497_Uncertainties_Trends_and_Hottest_and_Coldest_Years_of_US_Surface_Air_Temperature_since_1895_An_Update_Based_on_the_USHCN_V2_TOB_Data/figures/fig=1"]
More importantly, it needs to show how you've cut them up into regions.

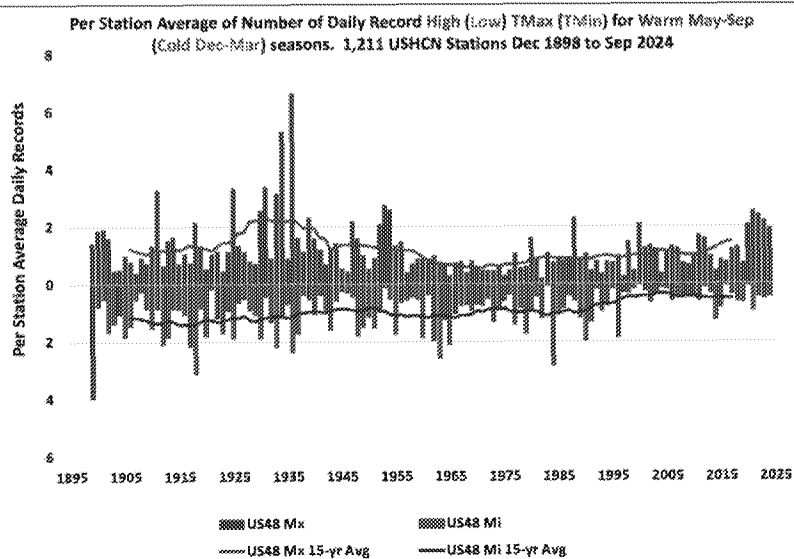
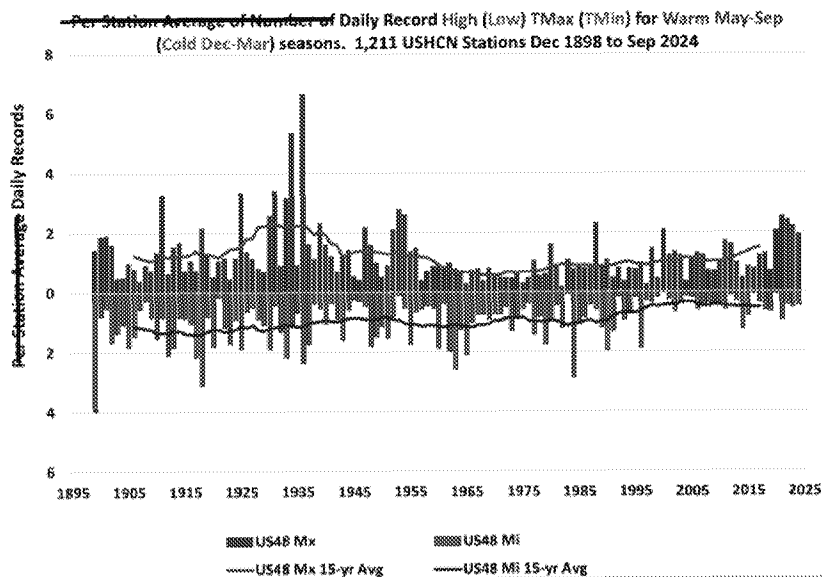


Figure 8.4.110 Number of daily record High (red) and Low (blue) for warm and cold seasons in the CONUS. The lines represent the 15-year running, centered average. Source: 1,211 USHCN stations supplemented as needed to achieve a minimum of 92% of observations in the 126-year period since Dec 1898.

The results indicate a common feature in many metrics of warm-season extremes in the CONUS—the exceptional heat of the 1920s and especially the 1930s, peaking in 1936. On a per-station average, 60% of the TMax records and 59% of the TMin records occurred in the first half of the period (1899–1961).

On the cold side, the Valentine's Day Arctic outbreak in Feb 1899 stands as the most extensive cold extreme experienced by the CONUS, with 1917–2nd. The frequency of cold records has declined, especially over the last quarter of the period in which only 13% of the extreme cold events were measured. In contrast, 25% of the extreme TMax records were achieved in the last quarter in accordance with statistical expectations. These general features have been noted in past assessments (IPCC AR5, IPCC AR6, NCA4, NCA5). Combining the two records the overall reduction in numbers of both cold and hot extremes over the past century indicates a climate less prone to extremes.

This pattern is also shown in Figure 8.4.211. For each station and for each year the hottest warm season and coldest cold-season temperatures were calculated and converted to anomalies relative to the station's long-term warm and cold season (respectively) averages. Then the differences between these were computed by station and geographically averaged over all stations, thus yielding an annual measure of the expected range of local extreme temperatures for each year. Figure 8.11 shows the 15-year trailing average of this measure which has clearly declined over the past century.

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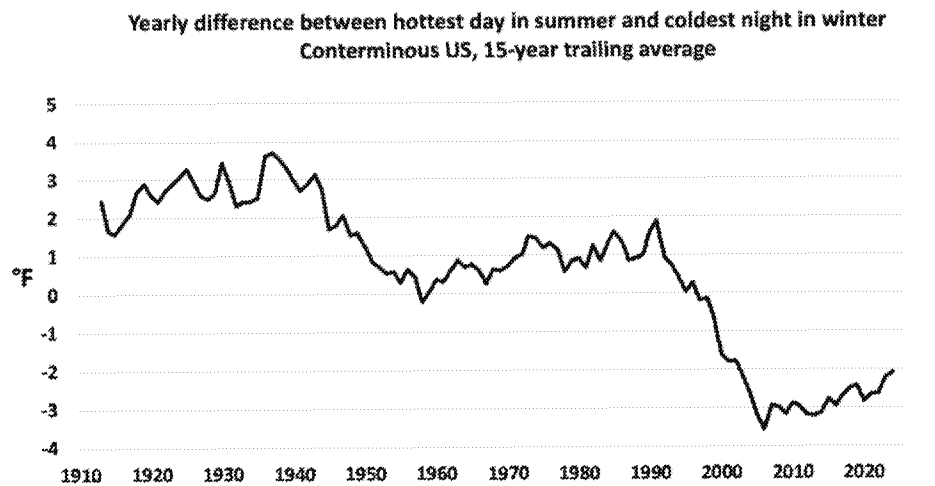


Figure 8.4.211. 15-year trailing average of the difference each year of each station's hottest warm-season TMax and coldest cold-season TMin relative to the long-term average.

The average difference for each station between the hottest summer TMax and coldest winter TMin has declined about 5°F in the past 126 years. The decline is due mostly to warming winter TMin, but

a decline in the magnitude of summer TMax is also a factor. The rise in TMin has been strongly related to the growing presence of manufactured surfaces around the weather stations over the last 100+ years (Spencer et al. 2025).

Summarizing Figures 8.10.4.1 and 8.4.2.11, while temperature extremes are regularly experienced in the US and attract a great deal of media attention, long term records show the US climate has become less extreme over time (milder) when measured in terms of the range between warm season maxima and cold season minima.

8.34.2 Exceedances of a heat threshold

Under the heading of "The Risk of Temperature Extremes is Changing", the most recent US National Climate Assessment report (NCA5) notes the increase in a threshold metric of number of days at or above 95°F, stating,

"The western US has been particularly affected by extreme heat since the 1980s..., experiencing a larger increase in days over 95°F, as would be expected given the greater warming in that region relative to the eastern US. Several major heatwaves have affected the US since 2018, including a record shattering event in the Pacific Northwest in 2021."

Are the occurrences of 95°F days changing? In a climate as varied as that of CONUS, threshold statistics can be misleading. A region with many stations which ~~that~~ have near 95°F TMax average temperatures in the summer might see large swings in the metric when only small changes in average temperature occur. Elsewhere with stations that either rarely or virtually always achieve 95°F TMax temperatures, a small change will not impact the results much at all. In the past 126 years, the average CONUS station experienced 129 days exceeding 95°F per 6-yr period, but the regional values range from 278 in the Southern Plains to 9 in the Northeast. Thus, one needs to view such threshold analyses with caution.

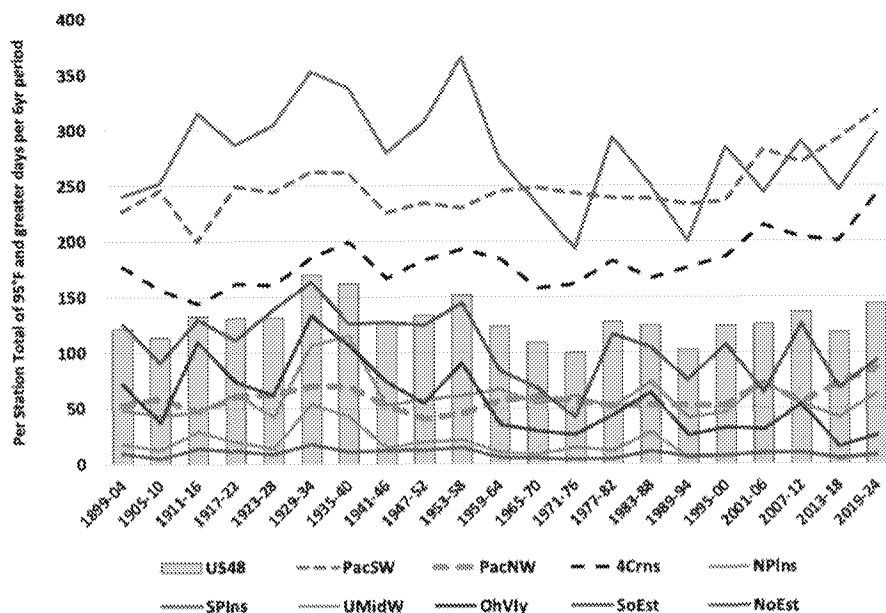


Figure 8.124.3. Total number of days $\geq 95^{\circ}\text{F}$ in 6-yr periods, US 48 (bars) and regions (lines).

In Fig. 8.12 4.3 we see that only three of the nine regions, all in the West, have experienced upward trends in the number of 95°F or hotter days (dashed lines). The CONUS as a whole has not and the other six regions have experienced declines.

The Pacific NW heatwave of 2021 is referenced as supportive information for of the NCA5 claim, an event we examined more closely in Section 6.4. The evidence indicates it was a “black swan” event, i.e., a single, unprecedented event in the existing record, not part of a suggesting it is not indicative of a pattern of increasing extreme heat. For example, the 5-day average tropospheric grid-point temperature anomaly over the Pacific NW during that event was $+10.9^{\circ}\text{C}$, the most extreme NH grid point summer anomaly in the 46 years from over 4 million grids. In contrast, the global anomaly during that time was virtually zero ($+0.03^{\circ}\text{C}$, Mass et al. 2024).

The heading “The Risk of Temperature Extremes is Changing” suggests positive trends are now being observed in threshold temperatures on a widespread basis, but that is not evidenced in the combined CONUS results of the figures above.

8.34.3 Heatwaves

Heatwaves (consecutive days that exceed an extreme threshold) have a greater societal impact than Of more impact than a single daily record. We measure is the phenomena of heatwaves, or consecutive days which exceed an extreme threshold. For this study, the metric will be the number of “Heatwave Days” here defined as the sum count of all days in May-Sep each year which that exceed

the 90th percentile and that occur lie within consecutive periods a run of at least six consecutive days in length. This is equivalent to the method used in NCA5 except that the reference period here is the entire record 1899-2024 while NCA5 limited truncated the reference period to 1961-1990, a cool episode time. By selecting 1961-1990, the That truncation occurrence of boosts positive results (days exceeding the 90th percentile) will be enhanced in periods warmer than the reference base period, especially if starting in 1960 and moving to the present (see *Urban Influences* below).

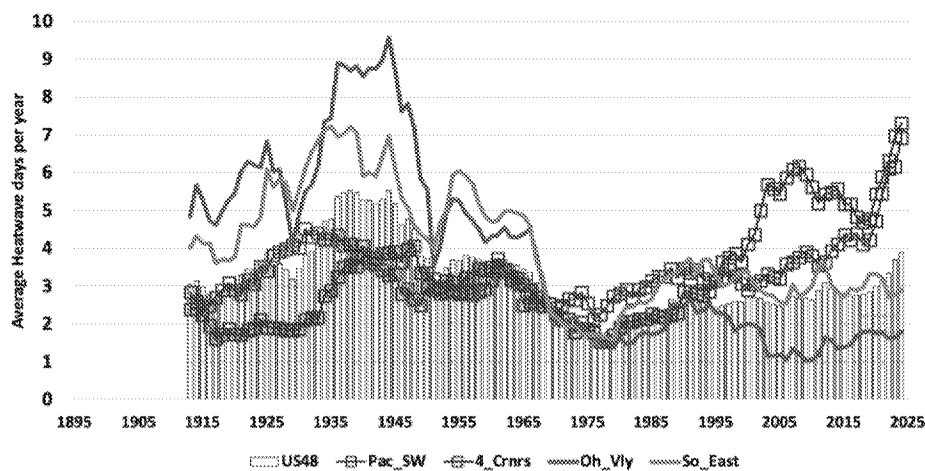


Figure 8.13 4.4 15-year trailing average of number of heatwave days per year per station in the CONUS (bars) and four regions: Pac_SW (purple squares, CA, NV), 4_Crnrs (red squares, AZ, NM, UT, CO), Oh_Vly (blue, MO, IL, KY, TN, IN, OH, WV) and So_East (green, MS, AL, GA, FL, SC, NC, VA).

Figure 8.13 4.4 indicates again the excessive heat of the first half of the 20th century, primarily in the eastern two-thirds of the nation, as seen in the regional values for the Ohio Valley and the Southeast as examples. The West has seen a recent increase of heatwave days and the two regions with the highest number are shown, the Pacific Southwest and the Four Corners (NCA5). This indicates that the background warm season circulation favored heatwaves in the eastern portions of the country in the first half of the 20th century, but in the 21st century the patterns have favored heatwaves in the West. For CONUS as a whole, heatwaves are no more common today than they were a century ago.

Of interest here is the regional variation of this metric. The four northern regions (Pacific NW, Northern Plains, Upper Midwest, and Northeast) on average experience 15 to 27 heatwave days per 15-year period. In contrast, the five southern regions (Pacific Southwest, 4-Corners, Southern Plains, Ohio Valley and Southeast) see 37 to 54 such days, essentially twice as many. This suggests the summer circulation pattern is more prone to stationary events in the southern regions while transient systems in the northern regions are more common and thus cut short these potentially longer events.

Urban influences

The NCA5 directs readers to the website [HYPERLINK "https://www.globalchange.gov/indicators/heat-waves"] (USGCRP 2023) to view the number of urban heatwaves by decade from the 1960s. The figure reveals shows a monotonic increase in each decade from 2 occurrences per year in the 1960s to 6 in the 2020s. The definition of a heatwave is an unusual but practical measure from aof human discomfort perspective—a period of at least 2 consecutive days when the minimum apparent minimum temperature (combination of temperature and humidity) exceeds the 85th percentile. Note too, the dataset is limited to the 50 largest U.S. cities in the US.

These increasing values since 1960 presented in USGCRP (2023) are entirely reasonable, but are unrelated to GHG emissions for at least two reasons unrelated to GHG emissions. Urbanization in these cities is a major factor in the rise of TMin relative to co-located TMax and relative to TMin at rural stations. Also, the 1960s was the coldest decade and 1970s the second coldest decade since the 1910's, so this starting date preconditions the time series to show increases. This does not dismiss the real rise in nighttime temperatures in major U.S. cities and the societal impacts associated with these changes. However, we note for a variety of reasons, that summer TMax (especially in rural areas) serves as better response variable for detecting potential changes in heatwaves influenced by changes in the background climate due, for example, to increasing GHGs (Christy et al. 2009). For the CONUS as a whole, the evidence in this section suggests GHG emissions have had little to no effect on heatwaves in the CONUS.

8.34.4 Extremes in daily precipitation.

Because precipitation involves a discrete phase change (water vapor to liquid), it is Due to its stochastic and episodic in character and therefore, precipitation requires careful statistical treatment to understand variability over long time periods (see 8.1 Introduction). The US National Climate Assessments (NCA4, NCA5) have highlighted an increase in the occurrence of the heaviest precipitation events (defined in different ways) primarily in the eastern half of the CONUS, especially the Northeast, when starting in either 1901 or 1958. Interestingly, the regional variations indicate that the largest increases in extreme events are in the Northeast and least the smallest in the West, which is a trend counter to the changes in temperature extremes shown above.

Commented [A13]: Stochasticity and LTP are really different things, but we somehow conflate them in this sentence. Or am I missing something?

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McKittrick and Christy (2019) examined long-term and consistent station observations of daily precipitation to test some of these NCA claims for the Southeast and West Coast. In neither case when the time series were extended back in time (as far as 1972 in some cases) or when starting later (1978), there were no were the trends significant trends for either region. For this report we updated these findings with similarly constructed observations from 29 stations on the Pacific Coast (1893ff from San Diego CA to Blaine WA, see Figure 8.14), 24 stations in the humid Southeast (1872ff from Austin TX to Washington DC, see Figure 8.15), and 21 stations in the Northeast (1888ff from Buffalo NY to Gardiner ME, see Figure 8.16). The results were as follows.

Pacific region:

- Average precipitation trend is significant (downwards) in Astoria, insignificant elsewhere.
- The trend in rainfall variance is positive and significant in Big Sur, insignificant elsewhere.
- The trend in daily maximum precipitation is positive and significant in Aberdeen and Big Sur and negative and significant in Newport (insignificant elsewhere).
- Averaged over all stations in the region none of these three trend parameters is statistically significant.

Southeast region:

- ~~The trend in average precipitation is positive and significant in Mobile and Quitman, insignificant elsewhere.~~
- ~~The trend in rainfall variance is positive and significant in Mobile, insignificant elsewhere.~~
- ~~The trend in daily maximum precipitation is positive and significant in Vicksburg and Norfolk, insignificant elsewhere.~~
- ~~Averaged over all stations in the region none of these three trend parameters is statistically significant~~

Northeast region:

- ~~The trend in average precipitation is positive and significant in 9 of 21 locations and in the region averaged overall.~~
- ~~The trend in rainfall variance is positive and significant in Portland, Albany and Buffalo, insignificant elsewhere.~~
- ~~The trend in daily maximum precipitation is positive and significant in Portland and Gardiner, insignificant elsewhere.~~
- ~~Averaged over all stations in the region the trend parameters for variance and maximum precipitation are not statistically significant.~~

~~In the Pacific region, over the whole sample, the trend in average precipitation trends downward, being significant only is negative and significant in Astoria, and insignificant elsewhere. The trend in rainfall variance increases, is positive and significant only in Big Sur, and insignificant elsewhere. The trend in daily maximum precipitation is positive and significant in Aberdeen and Big Sur and negative and significant in Newport and insignificant elsewhere. Averaged over all stations in the region none of these three trend parameters is statistically significant.~~

~~In the Southeast region over the whole sample the trend in average precipitation is positive and significant only in Mobile and Quitman, the trend in rainfall variance is positive and significant only in Mobile and the trend in daily maximum precipitation is positive and significant only in Vicksburg and Norfolk. Averaged over all stations in the region none of these three trend parameters is statistically significant.~~

~~The Northeast region exhibits a pattern of increasing average rainfall. The trend in average precipitation is positive and significant in 9 of 21 locations and in the region averaged overall. The trend in rainfall variance is positive and significant only in Portland, Albany and Buffalo and insignificant elsewhere and not in the regional average. The trend in daily maximum precipitation is positive and significant only in Portland ME and Gardiner ME and insignificant elsewhere and not in the regional average.~~

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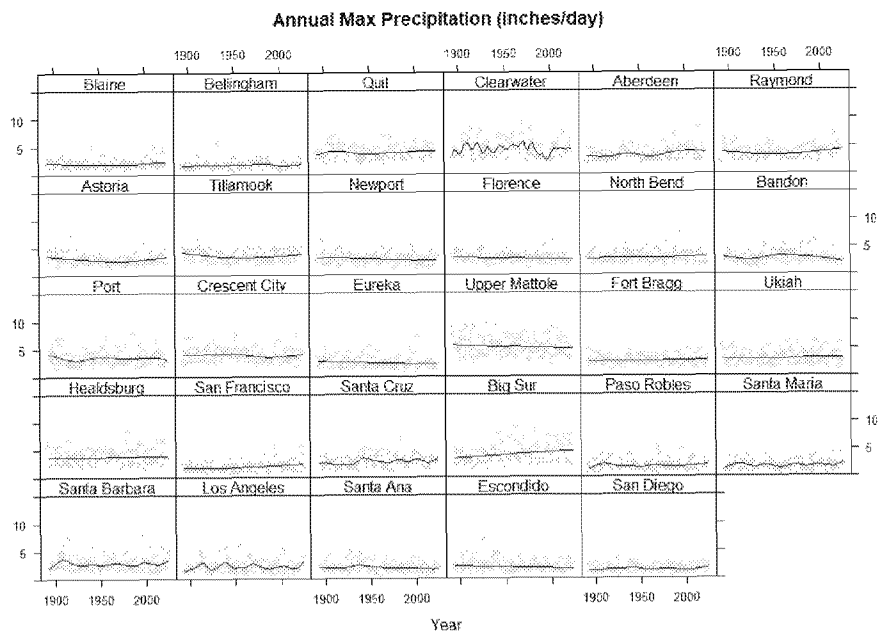


Figure 8.11 Annual maximum precipitation for 29 Pacific stations 1893 to present

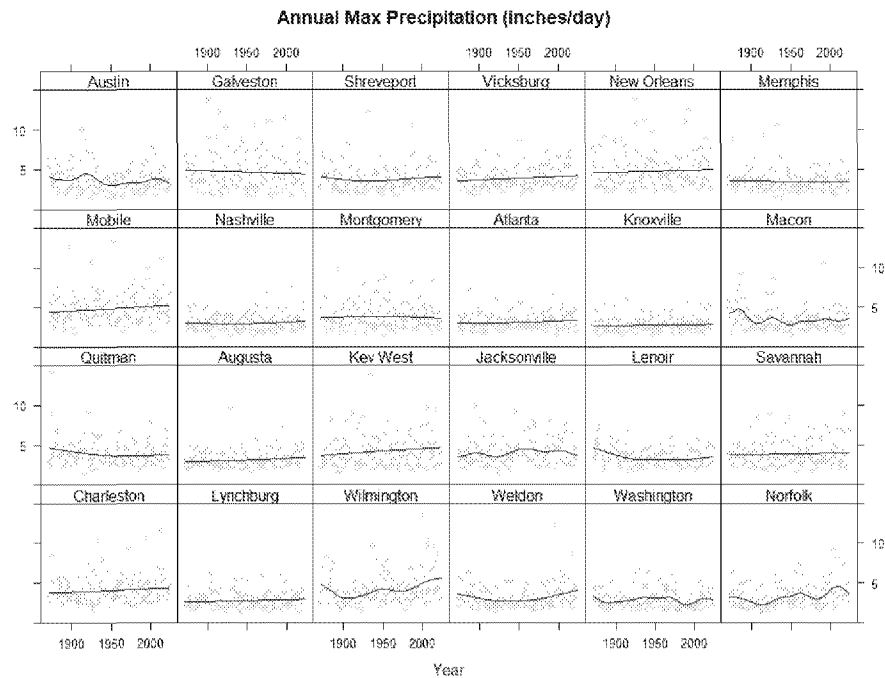


Figure 8.12 Annual maximum precipitation for 24 Southeast stations 1872 to present

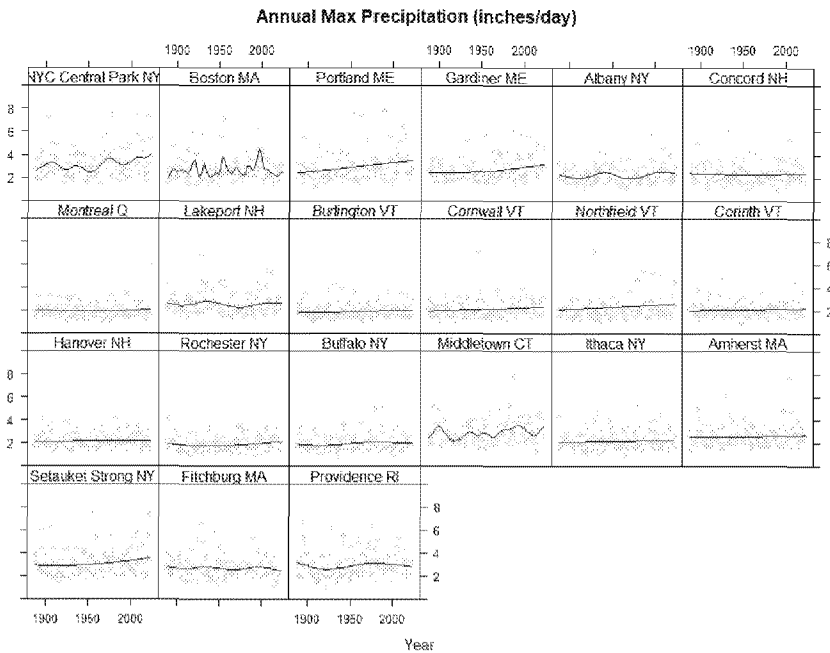


Figure 8.13 Annual maximum precipitation for 21 Northeast stations 1888 to present

Pacific Coast heavy rainfall events

The Pacific Coast receives considerable amounts of precipitation from Atmospheric River (AR) events which often last more than a day or two (e.g., Gershunov et al. 2017, Pan et al. 2024). The worst known such event in recent history was the Ark Storm that occurred between December 1861 and January 1862, which dumped nearly 10 feet of rain in parts of California and submerged the entire Central Valley for weeks under as much as 15 feet of water (Brewer 1930, Null and Hulbert 2007). Paleoclimate research has found six megastorms more severe than 1861–1862 in California during the last 1800 years, occurring at intervals of 300 years or so (Porter et al. 2011).

SIDEBAR: Perils of short data records

San Francisco provides a good case study of the limitation of using short historical samples to characterize natural variability of extreme events. Suppose we use a 130-year sample of daily San Francisco precipitation from 1895 to 2024 and we look for 3-day, 5-day, 14-day and 30-day rainfall records. The results are as shown in Table 8.12.

Event	Record (inches)	Year
3-day	6.94	2023
5-day	8.55	2023
14-day	12.62	2023

30-day 18.93 1998
Table 8.12: Extreme rainfall records, San Francisco, 1895-2024.

The records all cluster in the more recent data. 2023 appears to be an exceptional year and since it is near the end of the sample it would ~~might~~ point to the possibility ~~suggest~~ that the climate has shifted into a potentially more hazardous state, ~~perhaps as a result of human influences.~~

But the picture is very different if we use a sample that begins 45 years earlier, in 1850. If we extend the record back to 1850 the picture changes. Table 8.23 shows that the record-setting events ~~then~~ all happened in the 1860s. Furthermore 2023 is now not even in 2nd place but falls to 3rd or 4th. Also, comparing the records of the two charts the extreme precipitation events in 1862 and 1867 involved considerably more rainfall than the 1998 and 2023 events, with 14- and 30-day totals about 50 percent higher.

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Event	Record (inches)	Year	Rank of 130-yr extreme
3-day	8.85	1867	3
5-day	9.80	1867	3
14-day	19.05	1862	4
30-day	28.25	1862	2

Table 8.23: Extreme rainfall records, San Francisco, 1850-2024.

~~The~~ The characterization of the range of natural variability is made even more remarkable when paleoclimate evidence is examined. Porter et al. (2011) discovered that in the past 1,800 years at least six megastorms were more intense than the devastating 1861-62 ArkStorm that struck the region. Thus, ~~Evidently~~ such extreme events have impacted the region about every 300 years, though not since 1895.

This example illustrates the limitations of using relatively short climate periods (~130 years) to assess the character and range of natural variability in general and of extreme events in particular. Accurate representation of the full range of natural variability is necessary for any attribution analyses (see 6.4). Infrastructure planners, emergency management institutions and attribution scientists would understand the significant mischaracterization of the magnitude of a future extreme if based only on the last 130 years. In this case, a single time sample of 130 years provides an underestimation of the extreme value by up to 50% determined when adding only 45 more years of observations. Compared to millennial-scale paleoclimate evidence, an even greater underestimation would occur. ~~An important lesson is that the climate can deliver great surprises on its own even without human influences.~~

We examine occurrences of 5-day deluges as follows. In a 130-year span there are 26 5-year intervals. At each location we computed the 5-day precipitation totals throughout the year and selected the 26 highest values. A single year may have more than one of the 26 heaviest. Each of those can be thought of as 1-in-5yr events. If there are no trends in precipitation then the total number of these events across all stations should be evenly spread out on an annual basis ~~over the years~~. In Fig. 8.14-4.5 we show the distribution in time of these events. The deluges associated with the massive 1997-98 El Niño event are readily apparent. While erratic, as is typical of these types of precipitation metrics, there is no indication of a tendency to become more frequent over time.

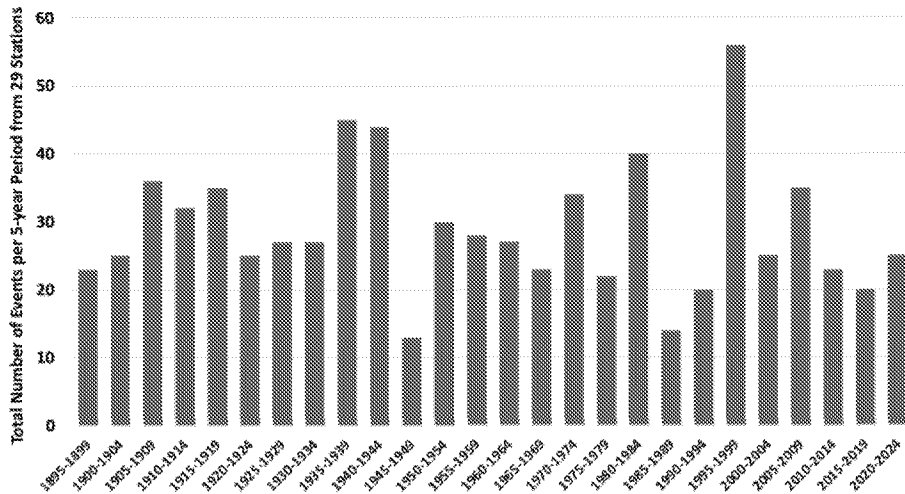


Figure 8.144.5. The time distribution by 5-year periods of the 26-heaviest occurrences for each station (i.e., nominal 1-in-5-year event).

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Southeast heavy rainfall events

The temporal pattern of 5-day totals of the 1-in-5yr heavy events in the humid Southeast (Figure 8.154.6) is generally unremarkable, though a cluster of higher values appears in 1995 to 2019. The increase in those years is due largely to the 4 northeastern-most stations of Wilmington NC, Weldon NC, Washington DC, and Norfolk VA. This confirms the pattern indicated in NCA4 and NCA5 of a tendency for an increasing frequency of heavy events, due to a temporal clustering of tropical storms from eastern NC to Maine discussed below. Otherwise, the remaining 20 stations show an unremarkable temporal distribution of heavy events.

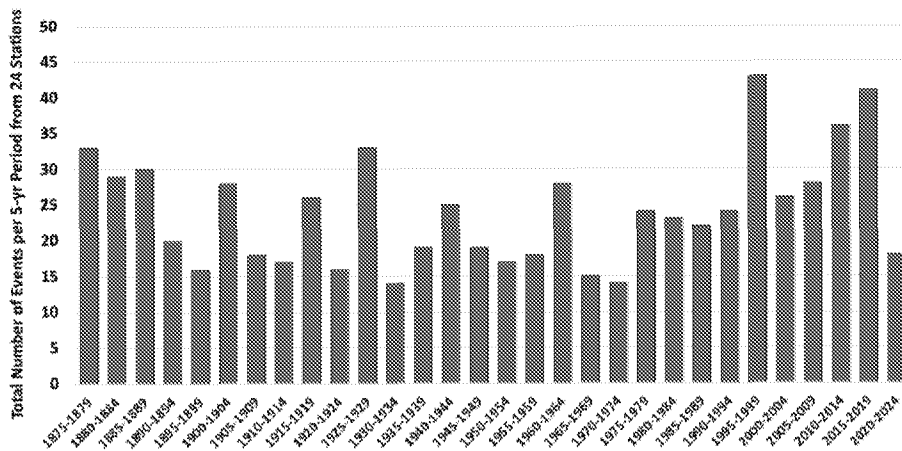


Figure 8.154.6. As above but for the 30 heaviest 1-in-5yr events for 24 stations in the humid Southeast from Austin TX to Washington DC in 5-year bins for 1875-2024.

Northwest heavy rainfall events

Fig. 8.164.7 shows the 27 (1-in-5yr) heaviest 3-day events for the last 135 years in 21 stations in the Northeast (including Montreal Canada). We use 3-day totals here as this produced the largest variations in time. In this region, 72% of the events occur during June to October and are dominated by tropical incursions of hurricanes, tropical storms or tropical storms that transition to extratropical systems. According to NCA4 and NCA5 this region experienced the largest increases in extreme events, so it shall be examined more closely.

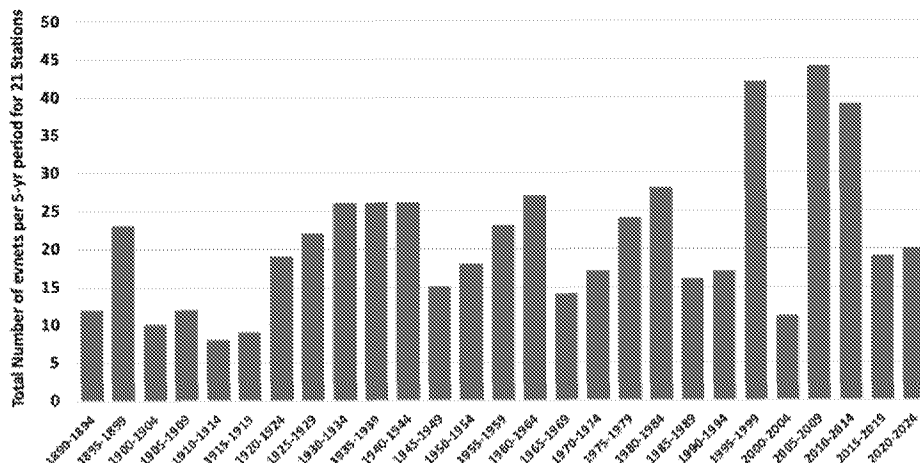


Figure 8.164.7. Time distribution of the heaviest 27 (1-in-5yr) heaviest 3-day precipitation events for 21 stations from NY to ME, including Montreal.

Howarth et al. (2019) report differences in the Northeast between two 18-year periods: 1979-96 and 1997-2014 (a similar region as in Fig. 8.16 that includes PA and NJ) of various precipitation extremes. One metric which indicated a dramatic increase (317%) was found for 24-hr events > 6 inches. This high increase is due to the very small numbers of such events of which there were only 6 in the first period and 25 in the second as reported for 58 stations. This high percentage increase is due to the very small numbers of the events; only 6 in the first period and 25 in the second. Most of the stations did not record such an event suggesting these erratic, episodic events over brief, 18-yr periods, need scrutiny by additional statistical methods.

Using the information in Fig. 8.164.7 over the same years as Howarth et al. we find a 51% increase in the frequency of heavy events between the two periods. One can see in Fig. 8.16 that it was unfortunate that Howarth et al. ended in 2014 prior to a return to the long-term average of such events.

A feature of Howarth et al. is the use of single day totals which is questionable because extreme events are often spread across the time of observation boundary. Thus stations measuring at 0700 LT versus those at Midnight will have differing results for a particular event which would then have major impacts on counting these events. We use the 3-day totals in Fig. 8.164.7 to be sure to capture the extent of these extreme downpours. In any case, we can confirm that the period 1997 to 2014 experienced a cluster of heavier events as Howarth et al. have documented.

Howarth's most remarkable claim (317% increase in 6" days) is potentially misleading because it is a threshold statistic (see Section 8.34.2 above) and a ratio of small numbers over a short period. The result is not representative of relative extreme events for the whole region since the majority of stations never experienced a 6" total. Fig. 8.16 above determines the same number of events for each station (27 heaviest events) whose heaviest values ranged from 4.4" to 12.5" and their 27th heaviest values ranged from 3.3" to 5.0". This analysis thus allows each station to be equally represented. In

other words, if there is a region-wide increase in heavy events, it should be seen in the sum of all stations. Note too that the period of record here is 135 years vs. 36 years of Howarth et al. Except for three 5-year periods between 1995 and 2014 there is nothing statistically remarkable about the results in Fig. 8.164.7.

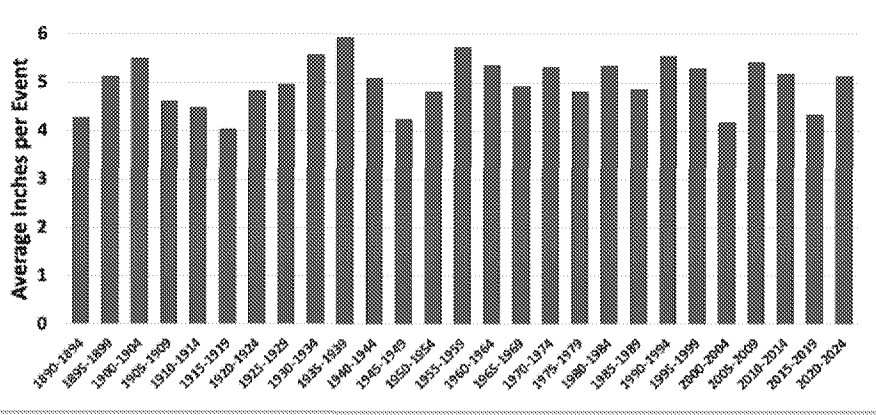


Figure 8.174.8. Average amount of precipitation falling in the 1-in-5yr events for the NE stations.

An interesting aspect of Northeast precipitation is that there has been no change in the amount of precipitation per heaviest event, as shown in Fig. 8.174.8. The trend is only $+0.02''/\text{decade}$. The highest amount, 1935-39, includes the Great New England Hurricane of 1938, one of the rare major (Category 3 or higher) hurricanes to strike the region. The results in Figs. 8.4.615 and 8.16.4.7 suggest that though there was an uptick in the number of events during the period 1995 to 2014, the events, individually, are not becoming more intense.

Jong et al. (2024) document the increase of tropical influences on precipitation events in the Northeast since 1959 and concluded, "The autumn extreme precipitation trend over the Northeast US is primarily attributed to tropical cyclone-related events since the 1990s." The question then becomes, was the temporal clustering of tropical systems in 1997-2014 which affected the Northeast a response to increasing GHGs? Jong et al. examined CMIP-6 model output which suggests that there will be fewer such systems in the 21st century but that the intensity of the rainfall events might increase. This conjecture is not seen in Fig. 8.17 where the amount per event has remained steady over the 135-year period.

For substantial urban areas there is some evidence to indicate the heaviest rainfall events may be redistributed due to the impact urban infrastructure has on the local weather (e.g., Pielke Sr. et al. 2011; Zhang et al. 2018; Yang et al. 2024). Yang et al. state, "Cities that experience compact development tend to witness larger increases in extreme rainfall frequency over downtown than their rural surroundings, while the anomalies in extreme rainfall frequency diminish for cities with

dispersed development.” While this is an important insight to consider, the effect on the specific stations used in this analysis is unknown, or at least not detectable in Fig. 8.17.

In summary, the evidence from the historical record of extreme precipitation events in the CONUS is generally not consistent from region to region so that inferences regarding trends and their projections are wrought with significant uncertainty. In most regions and perhaps all, it is our opinion that the very nature of the erratic and episodic character of extreme precipitation events renders the discovery of statistically significant changes, including a relationship to CO₂ concentrations, a result yet to be achieved (McKittrick and Christy 2019).

8.4510 Summary

To be inserted

Based on the content provided in the document, here are the five most important takeaways:

- Limited Detection of Anthropogenic Signals: The IPCC has asserted high confidence in detecting an anthropogenic signal in only 4 out of 34 weather impact categories, and medium confidence in 4 more. For the remaining 26 categories, no anthropogenic signal is claimed to be detected.
- Slow Emergence of Trends: Even under the most extreme forcing scenario (RCP8.5), the IPCC expects very few anthropogenic trends to emerge within this century for most weather impacts.
- Natural Variability Dominance: Natural variability continues to dominate patterns of extreme weather systems. Simple assertions of trend detection are often complicated by regional heterogeneity and trend reversals over time.
- RCP8.5 Scenario Implausibility: The document notes that the RCP8.5 scenario is described as an implausible high-end storyline, not a “base case” or “business-as-usual” projection.
- Conflicting Messages on Attribution: The document mentions that AR6 (IPCC Sixth Assessment Report) offers conflicting messages about the attribution of extreme weather to anthropogenic causes, highlighting the complexity and uncertainty in this area of climate science.

These takeaways emphasize the nuanced and complex nature of attributing extreme weather events to climate change, and the importance of considering natural variability and uncertainty in climate projections.

Commented [A18]: Out of curiosity (and perhaps utility), I fed the entire document (absent this section) into Anthropic's Claude-3.5-sonnet LLM and asked it what are the five most important takeaways. This is what it produced. I'd judge it not a bad start that will need some human improvement, which I'll undertake on the next iteration.

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Appendix: Review of IPCC and NCA Findings on Extreme Weather

The sources we review will be denoted as follows:

SREX: The IPCC *Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation* (2012)

AR5: The IPCC *Fifth Assessment Report Working Group 1* (2013).

AR6: The IPCC *Sixth Assessment Report Working Group 1* (2021).

NCA17: The *US Climate Science Special Report of the Fourth National Climate Assessment* (2017) Volume I Chapter 6.

8A.1 Overview: IPCC Assessment of signal emergence in extreme weather types (AR6 WG1 Table 12.12)

Table 8A.1 reproduces the findings of AR6 Table 12.12 which indicates, for 34 major weather event and impact types, whether a signal of anthropogenic forcing has been detected in the historical record (column 1), whether such a signal is likely to emerge by 2050 under the extreme RCP8.5 scenario (column 2) and whether it is likely to emerge by 2100 under RCP8.5 forcing (column 3). It should be borne in mind that the latter two columns suffer from the deficiencies of GCMs discussed in Chapter XV. And as we discussed in Ch X on attribution, AR6 offers three conflicting messages within the AR6 regarding about attribution of extreme weather. Nevertheless, we provide this Table is provided here for reference.

Several patterns stand out. First, detection of an anthropogenic signal is asserted with *high confidence* in only four out of the 34 weather impact categories an anthropogenic signal is asserted with *high confidence* in only four, and with *medium confidence* in a further four. For the rest, The IPCC does not *NOT* claim to have detected an anthropogenic signal in the remaining 26 categories. Of the four *high confidence* assertions, two are for changes in average temperatures (air and ocean), which hence are not measures of extreme weather. Also two. Further, two of the four *medium confidence* assertions are related to ocean chemistry and thus are likewise also not related to extreme weather. The IPCC does not *NOT* assert a detectable human influence on many non-temperature weather features such as wind, precipitation, flooding, and drought, etc.

Second, as shown in, columns 2 and 3 show that the IPCC expects very few such anthropogenic trends signals to emerge within this century, even under the most extreme forcing scenario. As we discuss in Section 4.2 the RCP8.5 scenario is an implausible high-end storyline, it is not a "base case" or "business-as-usual" projection. Yet even still. Even so, most weather impacts are not expected to exhibit *show* an anthropogenic signal this century. As will be clear from the underlying report text, natural variability dominates patterns of extreme weather systems and simplistic assertions of trend detection are frequently undermined by regional heterogeneity and trends reversals over time.

Climate Impact Driver Type	Climate Impact Driver Category	Already Emerged in the Historical Record?	Emerging by 2050 in Most Extreme CO ₂ Emissions Scenario?	Emerging by 2100 in Most Extreme CO ₂ Emissions Scenario?
Heat & Cold	Average air temperature	YES in most regions	YES	YES
	More heat extremes	YES in most regions	YES in land regions	YES
	Fewer cold extremes	YES in a few regions	YES in many regions	YES
	Less frost	NO	NO	NO

Wet & Dry	Average precip. (increase or decrease)	NO	YES (incr) YES (decr)	YES (incr) YES (decr)
	River flooding	NO	NO	NO
	Heavy precip & pluvial flood	NO	NO	YES in a few regions
	Landslide	NO	NO	NO
	Aridity	NO	NO	NO
	Hydrologic drought	NO	NO	NO
	Agricultural & ecological drought	NO	NO	NO
Wind	Fire weather	NO	NO	NO
	Average wind speed	NO	NO	NO
	Severe wind storm	NO	NO	NO
	Tropical cyclone	NO	NO	NO
Snow and Ice	Sand and dust storm	NO	NO	NO
	Snow, glacier & ice sheet	NO	YES in a few regions	YES Arctic snow
	Permafrost	YES	YES	YES
	Lake & river ice	NO	YES	YES
	Arctic sea ice	YES	YES	YES
	Antarctic sea ice	NO	YES	YES
	Heavy snowfall and ice storm	NO	NO	NO
	Hail	NO	NO	NO
	Snow avalanche	NO	NO	NO
	Relative sea level	NO	YES	YES
Coastal	Coastal flood	NO	NO	NO
	Coastal erosion	NO	NO	NO
	Average ocean temperature	YES	YES	YES
Open Ocean	Marine heat wave	NO	NO	NO
	Ocean acidity	NO	YES	YES
	Ocean salinity	YES	YES	YES
	Dissolved oxygen	YES (Pacific & S. Ocean)	YES	YES
Other	Air pollution weather	NO	NO	NO

From: Ross McKittrick <ross.mckitrick@gmail.com>
Sent: Thursday, May 15, 2025 3:46 PM
To: John Christy
Cc: Roy Spencer; Steven Koonin; Judith Curry; Travis Fisher
Subject: Re: Table 12.12

John, at this point we have IPCC Table 12.12 just column 1, with a discussion of cols 2&3 in the text. The email at 1:14PM ET has the current version attached.

On Thu, May 15, 2025 at 2:55 PM John Christy <climateman60@gmail.com> wrote:
All

We are interviewing candidates today for a lecturer and just got here. Was a final decision made on the 8.5 columns of the IPCC Table? If they are included, then comments could be made to demonstrate 8.5's uselessness.

John C.

On Thu, May 15, 2025 at 1:09 PM Roy Spencer <roywspencer@hotmail.com> wrote:
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To: 'Judith Curry' <curry.judith@cfanclimate.com>; 'Ross McKittrick' <ross.mckitrick@gmail.com>
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I am as well. Looks like we (at least Judy, Ross, and I) have converged.

SEK

From: Judith Curry <curry.judith@cfanclimate.com>
Sent: Thursday, May 15, 2025 1:16 PM
To: Ross McKittrick <ross.mckitrick@gmail.com>
Cc: Steven Koonin <steven.koonin@gmail.com>; Roy Spencer <roywspencer@hotmail.com>; John Christy <climateman60@gmail.com>; Travis Fisher <travis.scott.fisher@gmail.com>
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I'm good with this version, this works in the text and is a compromise for the other concerns that have been raised

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OK trying again:

screen shot of 12.12; only the first column; explanation in the text of why the other columns are omitted.

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The Table needs to be somewhere in our report, but I've got issues with presenting the last two columns (projections of emergence) for two reasons:

1. They are based on models that are not fit for that purpose and involve an implausible 8.5 scenario
2. Our discussions of the various climate impact drivers don't say much about projections (for good reason; see 1 above)

Of course, the counter argument is that we shouldn't butcher the table but reproduce it in full.

I'd be OK with a compromise that includes the last two columns but strengthens the scenario caveat the Ross has already put in there and further includes a model-bashing paragraph.

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Subject: Re: Table 12.12

The rationale for calling this subsection impact drivers is that we can include all of the topics in table 12.12 (not just extreme events)

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Let me know if this is ok.

Ross

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I'll take a stab at this and you all can tell me how it looks.

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9 Uncertainties in Attribution

9.1 Introduction

9.2 Attribution methods

9.3 Attribution of global warming

9.4 Attribution of impact drivers

9.5 Extreme event attribution

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Subject: Re: New folder: 01.Report Draft

This should get you in

https://www.dropbox.com/scl/fo/wahx6lpwzu33m5vyrr8x/ANTU1qAQJ-zXCFzP_gsJcOs?rlkey=l1z3qj9v46e1t5f4ywwwxq7p8c&dl=0

This is for the parent folder. Let me know if it doesn't work.

On Wed, May 14, 2025 at 6:41 PM Steven Koonin <steven.koonin@gmail.com> wrote:

Can you please send a link to the new folder?

Thanks.
Steven E. Koonin

> On May 14, 2025, at 15:27, Ross McKittrick <ross.mckittrick@gmail.com> wrote:

>

>

> Following our meeting today I created a new folder containing clean copies (all past tracked changes accepted) of all chapters.

> There are some marginal queries and in-line comments remaining to be resolved, missing Figure captions in a couple of places etc. If you are able to supply the missing info go ahead and do so. We will soon need to sign off on final text versions so please read through them.

> I propose that these should be the versions we talk through next week.

>

> Question: should there be a single list of references at the very end or should each chapter have its own reference list? Initially I thought the former but now I lean towards the latter.

>

From: John Christy <climateman60@gmail.com>
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Cc: Steven Koonin; Judith Curry; Ross McKittrick; Travis Fisher
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Sent: Thursday, May 15, 2025 2:10 PM
To: Steven Koonin; 'Judith Curry'; 'Ross McKittrick'
Cc: 'John Christy'; 'Travis Fisher'
Subject: Re: Table 12.12

I didn't have a strong opinion on this, so I'm good with the 3 of you agreeing.
-Roy

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I do get the counterargument that 8.5 is a fairy tale and climate models aren't fit for purpose

So a diagram clipping the IPCC 12.12 figure just to show column 1 is sort of ok. I think we'll need to do a vote on this one, after a few more arguments (pro/con) are presented

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Of course, the counter argument is that we shouldn't butcher the table but reproduce it in full.

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SEK

From: Ross McKittrick <ross.mckittrick@gmail.com>
Sent: Thursday, May 15, 2025 12:25 PM
To: Roy Spencer <roywspencer@hotmail.com>
Cc: Judith Curry <curry.judith@cfanclimate.com>; Steven Koonin <steven.koonin@gmail.com>; John Christy <climateman60@gmail.com>; Travis Fisher <travis.scott.fisher@gmail.com>
Subject: Re: Table 12.12

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-Roy

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Sent: Thursday, May 15, 2025 10:47 AM

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Let me know if this is ok.

Ross

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I think a potential difficulty there is having a chapter focused on weaknesses and uncertainties in attribution methodology, then taking a list of IPCC attribution results and presenting them at face value. It might seem opportunistic. However we could say something along the lines of: the general bias we are concerned about is the use of methods that downplay natural causes and overstate anthropogenic ones, but even still the IPCC draws a blank on anthropogenic influence on most impact drivers.

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9 Uncertainties in Attribution

9.1 Introduction

9.2 Attribution methods

9.3 Attribution of global warming

9.4 Attribution of impact drivers

9.5 Extreme event attribution

9.6 Summary

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Subject: Re: New folder: 01.Report Draft

This should get you in

https://www.dropbox.com/scl/fo/wahx6lpwzu33m5vyrr8x/ANTU1qAQJ-zXCFzP_gsJcOs?rlkey=11z3qj9v46e1t5f4ywwxq7p8c&dl=0

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Thanks.

Steven E. Koonin

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Sent: 5/15/2025 5:14:01 PM
To: Steven Koonin [steven.koonin@gmail.com]
CC: Roy Spencer [roywspencer@hotmail.com]; Judith Curry [curry.judith@cfanclimate.com]; John Christy [climatemanager60@gmail.com]; Travis Fisher [travis.scott.fisher@gmail.com]
Subject: Re: Table 12.12
Attachments: 9 Attribution.May15.[RM3].docx

OK trying again:

screen shot of 12.12; only the first column; explanation in the text of why the other columns are omitted.

On Thu, May 15, 2025 at 12:36 PM Steven Koonin <steven.koonin@gmail.com> wrote:

The Table needs to be somewhere in our report, but I've got issues with presenting the last two columns (projections of emergence) for two reasons:

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9 Uncertainties in Climate Change Attribution

9.1 Introduction

The Intergovernmental Panel on Climate Change (IPCC) distinguishes between detection of climate change and attribution of its cause.¹ As defined by the IPCC AR6 WGI Glossary (IPCC, 2025):

Detection: “Detection of change is defined as the process of demonstrating that climate or a system affected by climate has changed in some defined statistical sense, without providing a reason for that change. An identified change is detected in observations if its likelihood of occurrence by chance due to internal variability alone is determined to be small, for example, <10%.”

Attribution: “Attribution is defined as the process of evaluating the relative contributions of multiple causal factors to a change or event with a formal assessment of confidence.”

Both steps rely on statistical analysis. Detection focuses on whether changes are significant enough to stand out from random variation regardless of cause. Attribution involves comparison of observed events to model-generated counterfactuals. Since experimentation on the climate is not possible, attribution requires statistical inference to assess how much human activities, such as GHG emissions, versus natural factors, like volcanic eruptions, contribute to observed changes. Attribution methods assume all external and internal drivers of the system are known and represented.

There are ongoing scientific debates around attribution methods, especially for attributing extreme weather events to climate change. The IPCC has long cautioned that methods to establish causality in climate science are inherently uncertain and ultimately depend on expert judgement. The Fourth Assessment Report: The Physical Science Basis (Hegerl et al., 2007) explained it as follows:

‘Attribution’ of causes of climate change is the process of establishing the most likely causes for the detected change with some defined level of confidence... unequivocal attribution would require controlled experimentation with the climate system. Since that is not possible, in practice attribution of anthropogenic climate change is understood to mean demonstration that a detected change is ‘consistent with the estimated responses to the given combination of anthropogenic and natural forcing’ and ‘not consistent with alternative, physically plausible explanations of recent climate change that exclude important elements of the given combination of forcings’ (IPCC, 2001)... The approaches used in detection and attribution research described above cannot fully account for all uncertainties, and thus ultimately expert judgement is required to give a calibrated assessment of whether a specific cause is responsible for a given climate change.

The Fifth Assessment Report Working Group II makes the following statement:

¹ Note that the IPCC definition of “climate change” allows for both natural and human causes. This differs from the UNFCCC definition (and common usage), where the term is limited to human causes.

(Cramer et al., 2014):

“Two broad challenges to the detection and attribution of climate change impacts relate to observations and process understanding. On the observational side, high-quality, long-term data relating to natural and human systems and the multiple factors affecting them are rare. In addition, the detection and attribution of climate change impacts requires an understanding of the processes by which climate change, in conjunction with other factors, may affect the system in question.”

Because of the complexity of the causal chains in the climate system, investigation of these relationships is exceptionally challenging.

9.2 Attribution methods

The Intergovernmental Panel on Climate Change (IPCC) employs several attribution methods to assess the causes of observed climate changes, distinguishing between natural and human-induced factors. Below is a concise description of the key methods that have been used by the IPCC:

Optimal Fingerprinting uses linear regression to explain variations in observed climate data as a weighted sum of climate model simulations run with and without anthropogenic forcings. The data used in the regression model are weighted to try to minimize the influence of random noise and the estimation method is chosen to take account of climate model error.

Time Series Analysis exploits statistical differences between anthropogenic forcing and natural variability to see which dominates observed temperatures, and also uses variations in the timing of changes to determine if causal dependence across data series can be inferred.

Process-Based Attribution focuses on understanding the physical mechanisms behind observed changes. This approach combines observations, climate models, and theoretical understanding to attribute changes in specific processes to forcings. This approach is often used for regional climate phenomena, such as monsoon changes or polar amplification

Extreme Event Attribution assesses in the role of human influence in the likelihood of occurrence or intensity of extreme weather events (e.g. heat waves, droughts). Methods include:

- Probabilistic Event Attribution uses large ensembles of climate model simulations to compare observed events to model-generated counterfactuals
- Storyline Approach examines the physical processes driving an event and evaluates how anthropogenic forcings may have modified those processes

9.3 Attribution of global warming

Attribution statements for global warming in the three most recent IPCC Assessment reports are:

AR4: “Most of the observed increase in global average temperatures since the mid-20th century is *very likely* due to the observed increase in anthropogenic greenhouse gas concentrations.” (IPCC, 2007)

AR5: “It is *extremely likely* that more than half of the observed increase in global average surface temperature from 1951 to 2010 was caused by the anthropogenic increase in greenhouse gas concentrations and other anthropogenic forcings together. The best estimate of the human- induced contribution to warming is similar to the observed warming over this period.” (IPCC, 2013)

AR6: “The *likely* range of total human-caused global surface temperature increase from 1850–1900 to 2010–2019 is 0.8°C to 1.3°C, with a best estimate of 1.07°C. It is *likely* that well-mixed GHGs contributed a warming of 1.0°C to 2.0°C, other human drivers (principally aerosols) contributed a cooling of 0.0°C to 0.8°C, natural drivers changed global surface temperature by –0.1°C to +0.1°C, and internal variability changed it by –0.2°C to +0.2°C. It is *very likely* that well-mixed GHGs were the main driver of tropospheric warming since 1979.” (IPCC, 2021)

The AR4 and AR5 attribution statements reference the warming since the mid-20th century, the period when greenhouse gas emissions began rapidly increasing. The words “most” and “more than half” are deliberately imprecise, potentially ranging from 51 to 99% of the warming – presumably this imprecision is to account for structural uncertainties such as natural internal variability. The confidence level increases from *very likely* to *extremely likely* from AR4 to AR5. The structure of the attribution statement in the AR6 is fundamentally different, referencing the warming to the period 1850-1900. The AR6 attribution statement is more precise numerically, but with a lower level of confidence at “likely” – the AR6 attributes essentially all the warming to increases in greenhouse gases. The most confident statement from the AR6 relates to the tropospheric warming since 1979, using the words “main driver” and “*very likely*.”

There are three areas of substantive criticism of the IPCC’s assessment of the causes of the recent warming: inadequate assessment of natural climate variability, inappropriate statistical methods, and substantial discrepancies between models and observations. The last is discussed in Chapter 6, while this chapter discusses the first two factors. All of these criticisms are relevant to the IPCC’s policy-informing attribution of the recent warming, which also underpins extreme event attribution

9.3.1 Natural climate variability

IPCC AR6 states that natural external drivers since 1850-1900 have changed global surface temperature by –0.1°C to +0.1°C, and internal variability has changed it by –0.2°C to +0.2°C – on average having essentially no net impact on the warming since 1850-1900. This minimal contribution of natural variability has been disputed by a number of publications that question the magnitudes of solar variability and internal variability from the large-scale ocean circulations (R Connolly et al., 2021; W Soon, 2023).

If the Equilibrium Climate Sensitivity to CO₂ is low (Chapter 5), then natural climate variability becomes more important in the attribution of the recent warming. Further, if natural variability is

higher, then estimates of the Equilibrium Climate Sensitivity from the historical period would be lower (Scafetta, 2023).

Solar variability

IPCC AR5 concluded that the best estimate of radiative forcing due to Total Solar Irradiance (TSI) changes over the period 1750–2011 was 0.05 W/m^2 (Myrhe et al., 2014). IPCC AR6 acknowledges a much larger range of estimates of changes in TSI over the last several centuries, stating that the TSI between the Maunder Minimum (1645–1715) and the second half of the twentieth century increased by $0.7\text{--}2.7 \text{ W/m}^2$, a range that includes both low and high variability TSI data sets (Gulev, 2021). However, the recommended forcing dataset for the CMIP6 climate model simulations used in AR6 for attribution studies averages two data sets with low solar variability (Matthes, 2017).

While AR6 shows a substantially greater solar impact than does AR5, the overall impact on the climate was assessed to be small compared to anthropogenic forcing of climate change. However, the impact of solar variations on the climate is uncertain and subject to substantial debate – something that is not evident from the IPCC assessment reports (Lockwood, 2012; Connolly et al., 2021).

Exactly how TSI has changed over time has been a challenging problem to resolve. Since 1978, there have been direct measurements of TSI from satellites. However, the data exhibit non-negligible inconsistencies, and interpreting any multi-decadal trends in TSI requires comparisons of observations from overlapping satellites. There are several rival composite TSI datasets, disagreeing as to whether TSI increased or decreased during the period 1986–96 (the ACRIM gap; see Chapter 4). Further, the satellite record of TSI is used for calibrating proxy models, whereby past solar variations are inferred from sunspots and cosmogenic isotope measurements (Velasco Herrera et al., 2015).

There is substantial evidence for high solar activity in the second half of the 20th century (starting in 1959) and extending into the 1990's, before a decline in the early 21st century; this period is often termed the “Modern Maximum.” (Chatzistergos et al., 2023; Solanki et al., 2004; Usoskin et al., 2007). However, some scientists have concluded that it is not possible to be confident of any multi-decadal trend in TSI (Schmutz, 2021).

As a result of this uncertainty, some reconstructions for past values of TSI (since 1750) have low variability, implying a very low impact of solar variations on global mean surface temperature, whereas datasets with high TSI variability can explain more than 70% percent of the temperature variability since preindustrial times (Scafetta, 2013; Stefani, 2021). Hence, the choice of which TSI satellite record used in an analysis can substantially influence how much climate change is attributed to human versus natural forcings.

There is growing evidence that other aspects of solar variability, which are referred to as solar indirect effects, amplify TSI forcing or are independent of TSI forcing. Scafetta et al. (2023) suggests that ~80% of solar influence on climate may stem from non-TSI mechanisms. Candidate processes include: solar ultraviolet changes; energetic particle precipitation; atmospheric-electric-field effect on cloud cover; cloud changes produced by solar-modulated galactic cosmic rays; large

relative changes in the magnetic field; and the strength of the solar wind. Solar indirect effects are not included in climate models, although indirect methods of estimating these effects suggest significant influence. However, claims of non-TSI mechanisms influencing climate are uncertain and debated.

Natural variability of large-scale ocean circulations

Variations in global mean surface temperature are linked to recurrent large-scale variations in ocean circulation patterns. These circulation patterns include the Atlantic Multidecadal Oscillation (AMO), the Pacific Decadal Oscillation (PDO) and the El Nino-Southern Oscillation (ENSO). These circulation patterns influence ocean heat uptake and heat distribution, and also influence atmospheric circulation patterns and cloud distributions. There is some debate as to whether these variations are strictly internal to the climate system, or whether this variability can have a solar/astronomical origin or can be influenced by large volcanic eruptions.

While climate models simulate the large-scale ocean circulations and internal climate variability, the simulated magnitude in the multi-decadal band is too low in most models relative to observations, and the phasing of the variability in long-term climate simulations is not synced with the actual, observed climate variations (Kravtsov et al. 2024). Averaging multiple simulations from climate models effectively averages out the internal variations, leaving only the forced climate variability (e.g., CO₂ forcing). With most of the modern warming beginning in the late 1970's, the recent 50-year warming is on the same time scale as the multi-decadal oscillations of the AMO and PDO.

Here are summary statements from the IPCC AR5 and AR6 reports:

“Decadal variability in the Pacific, associated with the PDO or IPO, contributes significantly to regional and global temperature trends, but the relative contributions of internal variability and external forcing are difficult to disentangle in CMIP5 simulations.” (IPCC, 2013)

"Since AR5, there has been increased understanding of the role of internal variability, such as ENSO, PDO, and AMO, in modulating regional climate trends. However, limitations in simulating the exact timing and amplitude of these modes in CMIP6 models contribute to uncertainties in attributing observed changes to anthropogenic forcing (high confidence)." (IPCC, 2021)

The amplitude of the peak-to-trough impact of the multi-decadal oscillations on global temperatures has been assessed by the IPCC AR6: “The likely range of change due to internal variability is -0.2°C to +0.2°C (IPCC, 2021).” This implies a trough-to-peak change of 0.4°C. Over many centuries, any global temperature changes from the troughs and peaks will cancel out, with little to no net impact.

However, with a nominal timescale of 60-80 years for oscillations such as the AMO and PDO, the timing of the peaks and troughs can be confused with the secular trend. This becomes very relevant for attributing the warming for the 50 years since 1975, during which most of the warming has occurred. Even if climate models have the correct amplitude of the multidecadal oscillations, the

timing of the peaks and troughs is not adequately simulated, with each model and individual ensemble simulating a different phasing. Once the simulations of the ensemble members and different models are averaged, the natural internal variability contribution is averaged out, effectively cancelling the role of natural internal variability in the attribution process.

The Great Pacific Climate Shift of 1976-1977 was a notable climatic event characterized by an abrupt change in the North Pacific Ocean's atmosphere-ocean system that interacted with global climate patterns. This shift is closely associated with the Pacific Decadal Oscillation (PDO) that oscillates between warm and cool phases over decades. The 1976 shift marked a transition from a predominantly negative (cool) PDO phase (1947–1976) to a positive (warm) phase (1977 through 2000), with significant implications for global and regional climate patterns including the frequencies of El Niño and La Niña events. The Great Pacific Climate Shift coincided with the beginning of a period of accelerated global warming (REF TO A FIG OF GLOBAL TEMP ANOMALIES ELSEWHERE IN DOC) When the Great Pacific Climate Shift is accounted for in climate attribution analyses since 1950, it has been found that 40 percent or more of the warming in the second half of the 20th century was caused by natural internal variability (McLean et al., 2009; Tung and Zhou, 2013; Chylek et al., 2016; Scafetta, 2021).

9.3.2 Optimal fingerprinting

Optimal fingerprinting is a statistical technique introduced by Allen and Tett (1999) that compares observed climate data to climate model simulations to identify patterns (or "fingerprints") associated with human or natural forcing. It involves taking a vector of observed climate changes, such as warming rates in locations around the world, and decomposing them into a weighted sum of "signals", which are analogues to the observations generated by climate models with different types of forcings. The weights are chosen using a regression method called Total Least Squares. The analysis commonly uses just two signals, one generated by models using only anthropogenic forcings and one using only natural forcings. If the estimated weighting coefficient attached to a signal is significantly different from zero, then that signal is said to be "detected". If it is close to 1.0, then the model generating the signal is said to be consistent with observations. If it is less than 1.0, then the model signal for that forcing is too strong and needs to be scaled down, and vice-versa. Both the observed data and the signals are weighted using a model-generated estimate of patterns of randomness in the climate system so as, in principle, to put maximum weight on regions where natural variability is minimized.

Optimal fingerprinting is the primary tool for attribution in the climate literature. Studies applying it have been cited thousands of times, and it has been prominently featured by the IPCC since the 2001 Third Assessment Report. One of its inherent weaknesses is that results depend on assumptions about the accuracy of climate models, especially regarding their representation of natural variability (IPCC AR5 Ch 10.2.3).

Additionally, a series of papers by McKittrick (McKittrick 2022a, 2022b, 2023, 2025) has challenged the optimal fingerprinting method, arguing that it is inherently unreliable and that commonly used practices in econometrics can provide more valid results. Statistical theory requires that for regression models to yield unbiased coefficients, a set of assumptions called the Gauss-Markov conditions must hold. McKittrick (2022a) argued that the Allen and Tett (1999)

methodology violates the Gauss-Markov conditions, leading to potentially biased and inconsistent fingerprinting coefficients, undermining the reliability of the method. Chen et al. (2023) confirmed this analysis and argued that the method could yield unbiased results but only under very stringent assumptions. McKittrick (2022b) and (2023) raised a further concern that climate scientists—virtually alone among scientific disciplines—have used an estimation method called Total Least Squares (TLS) to estimate anthropogenic greenhouse gas signal coefficients, despite its tendency to be unreliable unless some strong assumptions hold that in practice are unlikely to be true. Under conditions which easily arise in optimal fingerprinting, TLS yields estimates with large positive biases. Thus, any study that has used TLS for optimal fingerprinting without verifying that it is appropriate in the specific data context has likely overstated the result.

McKittrick (2025) presented an empirical example comparing the results of conventional optimal fingerprinting against methods drawn from mainstream econometrics which are known to be valid for the specific application of signal detection. While the IPCC optimal fingerprinting method yields an anthropogenic signal coefficient close to 1.0 on a global temperature data set spanning 1900 to 2010, consistent estimation yields a coefficient around 0.4, which rises to about 0.65 on data spanning 1980 to 2010, implying the model response to greenhouse gases needs to be scaled down by about half to optimally match observations. The natural forcing signal coefficient, by contrast, is between 2.0 and 4.0, implying the climate model signals of natural forcing need to be scaled up two-to four-fold to match observed climate change. The fingerprinting coefficients estimated in McKittrick (2025), when used to scale the average sensitivity of the climate models used to generate the forcing signals in his data set, imply a Transient Climate Sensitivity of 1.4°C, which matches the estimate by Lewis (2022) using a different estimation method and multiple independent data sets.

While these analyses do not prove that all of the results from using the IPCC optimal fingerprinting method are wrong, it does show that the basis on which they were believed to be correct is non-existent – hence reducing confidence in the results.

9.3.3 Time series methods

The IPCC (AR5 WGI 10.2.2) drew attention to alternative approaches of assessing causality that emerged from the time series econometrics literature. They have the advantage of not depending on assumptions about the accuracy of climate models, but their disadvantage is they depend on assumptions about the data generating process underlying climate and forcing data that are not straightforward to test. The methods, now referred to as climate econometrics, use the tools of unit root testing, Granger causality and cointegration analysis, all of which are familiar in economics and finance and which are slowly being adopted in climate science. Time series analysis methods hold out the possibility of determining whether anthropogenic or natural forcings are the primary drivers of climate change without requiring the use of climate models, although key questions remain unsettled (e.g. Dergiades et al. 2016, Balcombe et al. 2019, Dagsvik et al. 2020, Razzak 2022, Dagsvik and Moen 2023).

Granger causality modeling is a tool for determining directions of influence in data series that move together. “Granger causality” is a statistical, not a physical, concept. If knowing the current value of one variable significantly improves the forecast accuracy of another variable we can infer a causal connection exists; this is called Granger causality. The modeling tools, called

vector autoregression, measure direct impulse-response patterns and feedbacks. An application to the well-known Vostok ice core data revealed an error by Al Gore in his documentary *An Inconvenient Truth*. Gore showed the data and drew attention to the coherence of temperature and CO₂ changes over a 440,000 year span, which he asserted was due to CO₂ driving temperature changes. But temperature changes can also affect atmospheric CO₂ levels. Davidson et al. (2015) examined the series and found that temperature Granger causes CO₂ but not the reverse. In other words on the time scales represented in the Vostok data the coherence in the series is primarily due to the influence of temperature on CO₂ levels not the feedback going from CO₂ to temperature.

In summary, the main statistical methods for attributing causation in climate data are optimal fingerprinting and time series analysis. Applications of the Allen and Tett (1999) optimal fingerprinting method dominate the attribution literature and have underpinned past IPCC conclusions, but results depend on the accuracy of climate models and the method has recently been criticized as inherently biased. Time series methods do not depend on climate models but require assumptions of their own and have generated results that have thus far not converged on a consensus.

9.4 Attribution of climate impact drivers

The IPCC (Ranasinghe et al. 2021) defines “climate impact drivers” or CIDs as “physical climate system conditions (e.g., means, events, extremes) that affect an element of society or ecosystems.” Hence CIDs are those features of the weather and climate system of primary interest when assessing the impacts of climate change since they potentially affect humans and the natural world. For instance, under the heading “Heat and Cold” CIDs are identified as mean air temperature, extreme heat, cold spells and frost. The IPCC also points out that CIDs are not necessarily harm-related: depending on the system in question they can be detrimental, neutral, beneficial or a combination.

The first column of Table 12.12 in Ranasinghe et al. (2021, p. 1856), reproduced here as Table 9.1, summarizes the AR6 assessment of whether a signal of attributable anthropogenic influence has emerged across all major CIDs. One of the themes of this chapter is that attribution methods used by the IPCC tend to overstate the anthropogenic influence and understate the role of natural variability. Nonetheless a striking feature of that summary table is how few CIDs exhibit an anthropogenic signal sufficient to distinguish them from natural variability.

Climatic Impact-driver Type	Climatic Impact-driver Category	Already Emerged in Historical Period
Heat and Cold	Mean air temperature	1
	Extreme heat	2
	Cold spell	3
	Frost	
Wet and Dry	Mean precipitation	
	River flood	
	Heavy precipitation and pluvial flood	
	Landslide	
	Aridity	
	Hydrological drought	
	Agricultural and ecological drought	
	Fire weather	
Wind	Mean wind speed	
	Severe wind storm	
	Tropical cyclone	
	Sand and dust storm	
Snow and Ice	Snow, glacier and ice sheet	
	Permafrost	
	Lake, river and sea ice	13
	Heavy snowfall and ice storm	
	Hail	
	Snow avalanche	
Coastal	Relative sea level	
	Coastal flood	
	Coastal erosion	
Open Ocean	Mean ocean temperature	
	Marine heatwave	
	Ocean acidity	
	Ocean salinity	13
	Dissolved oxygen	14
Other	Air pollution weather	
	Atmospheric CO ₂ at surface	
	Radiation at surface	

High confidence of decrease
Medium confidence of decrease
Low confidence in direction of change
Medium confidence of increase
High confidence of increase

Table 9.1: Reproduction of column 1 of Table 12.12, IPCC AR6 Working Group I report. Emergence of anthropogenic signal in historical period for CIDs shown. White: no signal detected. Blue and orange: change detected (decrease or increase) and confidence level as indicated in color legend.

Out of the 33 weather impact categories an anthropogenic signal is asserted with *high confidence* in only five, and with *medium confidence* in a further four. (Note that one of the CIDs is an increase in CO₂ levels, and since it is a tautology to attribute this to increased CO₂ levels this CID can be ignored.) For the rest the IPCC does not claim to have detected anthropogenic drivers. Of the five *high confidence assertions*, two are for changes in average temperatures (air and ocean) hence are not measures of extreme weather. Also two of the four *medium confidence* assertions are related to ocean chemistry and thus are likewise not related to extreme weather. The IPCC does not assert a human influence on many non-temperature weather features such as wind, precipitation, flooding, drought etc.

Columns 2 and 3 of IPCC Table 12.12 report on whether anthropogenic signals are expected to emerge this century under RCP8.5, the most extreme forcing scenario. We omitted these columns in part because they refer to whether climate models project signals will be detectable in the data, but this is a very different question than the one that concerns us here, namely whether a signal has been detected in historical data. Additionally, as we discuss in Chapter 4 the RCP8.5 scenario is a misleading and implausible high-end storyline, it is not a “base case” or business-as-usual projection. Even still it is worth noting that the columns in AR6 Table 12.12 indicate most weather impacts are not expected to exhibit an anthropogenic signal this century.

As we discussed in Chapter 7 natural variability dominates patterns of extreme weather systems and simplistic assertions of trend detection are frequently undermined by regional heterogeneity and trend reversals over time. Table 9.1 makes the related point that, again contrary to popular belief, attribution of changes in most extreme weather types to human influence is not currently possible. Taking wind as an example, the IPCC claims that an anthropogenic signal has not emerged in average wind speeds, severe windstorms, tropical cyclones or sand and dust storms, nor is one expected to emerge this century even under an extreme emissions scenario. The same applies to drought and fire weather.

9.5 Extreme event attribution (EEA)

Examining the IPCC’s treatment of extreme weather and climate event attribution more broadly, the AR6 provides an ambiguous assessment of the role of anthropogenic warming that differs between chapters. Chapter 11 of WG1 states (Seneviratne et al., 2021):

“Evidence of observed changes in extremes and their attribution to human influence (including greenhouse gas and aerosol emissions and land-use changes) has strengthened since AR5, in particular for extreme precipitation, droughts, tropical cyclones and compound extremes (including dry/hot events and fire weather). Some recent hot extreme events would have been extremely unlikely to occur without human influence on the climate system.”

By contrast, as noted, Chapter 12 of WG1 (Table 12.12) paints a different picture – presumably, the expert judgment of different groups of authors for the two chapters came to different conclusions (Ranasinghe, 2021):

- High confidence in an increase in extreme heat events in tropical regions where observations allow trend estimation and in most regions in the mid-latitudes, medium confidence elsewhere

- Medium confidence in a decrease in extreme cold events in Australia, Africa and most of northern South America where observations allow trend estimation
- No evidence of emergence in the historical period of a change in river floods, heavy precipitation, drought, fire weather, severe wind storms, and tropical cyclones

While the overall issue of detecting changes in extreme weather events and their attribution remains ambiguous, most of the activity in this area relates to the attribution of single extreme weather events. The most prominent effort is the World Weather Attribution (WWA; worldweatherattribution.org), which is an international research initiative that focuses on extreme event attribution analyzing how climate change influences the likelihood and intensity of extreme weather events. The approach used by the WWA runs large ensembles of regional climate models to compare the event in today's climate, versus a pre-industrial counterfactual climate without human-caused warming.

WWA plays a prominent role in linking extreme weather to climate change and its press releases attract considerable public and policy discussions. However, the WWA's tendency to promote non-peer-reviewed findings, funding ties, open admission that they shape their analyses to serve purposes of litigation and other methodological challenges have sparked controversies, with critics questioning the robustness and impartiality of its conclusions (Pielke Jr. 2024). Despite these issues, WWA's work continues to shape climate science and media narratives. Technical criticisms of the approach include: neglect of a formal detection process; an implicit assumption that 100% of the post-industrial warming is caused by CO₂; and failure to adequately account for natural internal climate variability.

Because EEA is relatively new many basic methodological issues have yet to be settled in the expert literature. An important challenge is the lack of data. Extreme events are by definition rare. Many analyses of extreme event types (including the US National Assessment Reports) only evaluate data since 1950 or 1970. However, as emphasized by Chapter 7, many of the worst extreme weather and climate events in U.S. history occurred prior to the first half of the 20th century including in the early 19th century. And if paleoclimate reconstructions are considered, it becomes very difficult for an event to pass the detection thresholds of exceeding what is expected from natural variability, particularly if a reasonably sized geographic region is considered.

Another challenge is defining the event under study. There is a longstanding literature in statistics and econometrics on the challenge of analyzing data with outliers. The issue arises because a data series establishes a probability distribution defining the expected range of observations. If an outlier is observed it might indicate that the underlying process giving rise to the data distribution has changed (which in the weather context would mean a climatic change has been detected) or that the underlying process has multiple regimes each with a different probability distribution, in which case observing an outlier simply means we were temporarily in a different regime, but the system itself was unchanged. If a time series contains only a single outlier event at the end of the series it is not possible to determine which model is the correct one (Chen and Liu 1993). For instance, there might be an "ordinary" weather regime that yields a distribution of summer daytime highs in a particular coastal region, and a second "heatwave" regime that kicks in when an inland blocking event occurs, which yields a temperature distribution centered 15°C higher than the first one. A day with temperatures 13°C above normal would either be an extreme heat anomaly under

the first regime or a somewhat cool event under the second, and we have no way in this case of knowing on statistical grounds which view is correct.

Visser and Petersen (2012) and Sardeshmukh et al. (2015) both point out that different distributions may fit observed data equally well but yield very different implications about the likelihood of a specific weather event. Visser and Petersen argue that, in view of the deep uncertainties of extreme weather analysis drawing a connection between individual events and global climate change should be avoided. Furthermore the existence of an outlier at the end of a data series poses the problem that estimates of the event probabilities will be biased whether the outlier is included or excluded (Barlow et al. 2020). Methods to eliminate the bias have not yet been established, leading some experts (e.g. Miralles and Davison 2023) to argue that in settings in which a data series contains a single extreme event at the end, estimation of a return period for the extreme event will be so biased and uncertain it should be avoided altogether.

In spite of these concerns, the U.S. is presently considering something like the WWA, which is being investigated by a NASEM Panel on Attribution of Extreme Weather and Climate Events and their impacts (NASEM, 2025).

A case study from a recent high impact extreme events in the U.S. is provided to illustrate the challenges and ambiguities in attributing the frequency and intensity of extreme weather events to human-caused warming.

9.4.1 Case study – 2021 Western North America heat wave

The 2021 Western North America heat wave was an extreme heat wave that affected much of Western North America in late June 2021. In particular, surface temperature records were set in Portland, OR (116°F; previous record 107°F) and Seattle, WA (108 °F; previous record 103°F) (Mass et al., 2024).

The WWA team garnered international headlines for their analysis and provided the following attribution statements (WWA, 2021; Philip et al., 2022):

- Based on observations and modeling, the occurrence of this heatwave was virtually impossible without human-caused climate change.
- The event is estimated to be about a 1 in 1000-year event in today’s climate.
- The event would have been at least 150 times rarer without human-induced climate change.
- This heatwave was about 2°C hotter than it would have been if it had occurred at the beginning of the industrial revolution (when global mean temperatures were 1.2°C cooler than today).

But an important caveat to the first claim is that other researchers concluded, based on historical weather data, that while a heat wave of the magnitude observed was indeed virtually impossible without anthropogenic climate change, it was also virtually impossible *with* climate change. Bercos-Hickey (2022) noted “these temperatures were virtually impossible under any previously experienced meteorological conditions, with or without global warming.” McKinnon and Simpson (2022) stated “the most likely explanation remains that the weather event itself was ‘bad luck.’”

The 2023 Oregon Climate Assessment (Fleischman 2023) concluded that the heat dome would have formed even without climate change and “There is no evidence that the highly unusual combination of weather features that drove the heat dome were made more likely by climate change, and climate models do not project an increase in the frequency of high-pressure ridges over the Pacific Northwest” (Fleischman 2023 p. 49).

Mass et al. (2024) summarizes the proximate sequence of compound events leading to the heat wave. There was a record-breaking midtropospheric ridge over the Pacific Northwest, forced by a tropical disturbance in the western Pacific. This produced record-breaking midtropospheric temperatures, strong subsidence in the lower atmosphere, low-level easterly flow that produced downslope warming on regional terrain and the removal of cooler marine air, and an approaching low-level trough that enhanced downslope flow. The event occurred at a time of maximum solar insolation, and drier-than-normal soil moisture. Using a storyline approach, Mass et al. assessed that there is no trend in drought and dry soils in the Pacific Northwest; there is no evidence of global warming producing stronger ridges of high pressure, and no observed trend in heat waves or record temperatures in the region. They concluded that although anthropogenic warming may have contributed as much as 2°F to the magnitude of the event, there is little evidence of further amplification of the event from increasing greenhouse gases.

A statistical analysis of a model-based attribution study of this heat wave was conducted by Bercos-Hickey et al. (2022). Because this event is a far outlier and far above the bounds of Generalized Extreme Value distributions fitted from historical data, they concluded that estimates of return times, quantitative changes in event magnitude and frequency, and probability of the extreme temperatures such as provided by the WWA are not accurate and should be interpreted as having low confidence. They found that hindcast attribution methods using an ensemble of regional climate models, combined with Pearl (2009) causal inferences, can provide limited and conditional information about the magnitude of the human influence on this heatwave – they provided a more highly constrained estimate that human activities caused a ~1.4°C–1.8°F increase in the daily maximum temperatures.

Zeder et al. (2023) also concluded that the methods employed by Philip et al. (2022) tend to overstate the rarity of extreme heat waves, leading to a biased perception of the effect of climate change on the heatwave event: “The tendency to overestimate the return period of observed extreme heatwave events may fuel the impression that seemingly impossible heatwave extremes are currently clustering at an unprecedented rate.”

The 2021 Western North America heatwave was a rare and unprecedented compound weather event, that broke century-old temperature records by as much as 9°F. While the WWA team received worldwide publicity for their rapid attribution claims blaming anthropogenic climate change, subsequent peer-reviewed analysis showed that the rare event was not made more probable by global warming.

9.5 Summary

There is an ongoing scientific debate around attribution methods, particularly in attributing extreme weather events to climate change. The IPCC has long cautioned that methods to establish causality in climate science are inherently uncertain and ultimately depend on expert judgement.

There are two areas of substantive criticism of the IPCC assessment of the causes of the recent warming: inadequate assessment of natural climate variability, and inappropriate statistical methods.

Detection of extreme weather events is challenged by their rarity, requiring a long data set and a choice of region and spatial scale to evaluate their occurrence against the background of natural weather and climate variability.

The most robust attribution statements for an extreme event relate to an incremental change (e.g. a temperature change in degrees or percent change in rainfall). Statements related to return times, quantitative changes in event magnitude and frequency, and probability of the extremes are not accurate owing to an inadequate amount of data, and are made with low confidence. There is no evidence in a change of weather or climate regime patterns from increasing greenhouse gases that would amplify or dampen extreme weather events, beyond basic thermodynamic considerations.

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<https://rogerpielkejr.substack.com/p/weather-attribution-alchemy>

From: Steven Koonin <steven.koonin@gmail.com>
Sent: Thursday, May 15, 2025 12:37 PM
To: 'Ross McKittrick'; 'Roy Spencer'
Cc: 'Judith Curry'; 'John Christy'; 'Travis Fisher'
Subject: RE: Table 12.12

The Table needs to be somewhere in our report, but I've got issues with presenting the last two columns (projections of emergence) for two reasons:

- 1) They are based on models that are not fit for that purpose and involve an implausible 8.5 scenario
- 2) Our discussions of the various climate impact drivers don't say much about projections (for good reason; see 1 above)

Of course, the counter argument is that we shouldn't butcher the table but reproduce it in full.

I'd be OK with a compromise that includes the last two columns but strengthens the scenario caveat the Ross has already put in there and further includes a model-bashing paragraph.

SEK

From: Ross McKittrick <ross.mckittrick@gmail.com>
Sent: Thursday, May 15, 2025 12:25 PM
To: Roy Spencer <roywspencer@hotmail.com>
Cc: Judith Curry <curry.judith@cfanclimate.com>; Steven Koonin <steven.koonin@gmail.com>; John Christy <climateman60@gmail.com>; Travis Fisher <travis.scott.fisher@gmail.com>
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- 9.6 Summary

Let me know if you like this idea

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9 Uncertainties in Climate Change Attribution

9.1 Introduction

The Intergovernmental Panel on Climate Change (IPCC) distinguishes between detection of climate change and attribution of its cause.¹ As defined by the IPCC AR6 WGI Glossary (IPCC, 2025):

Detection: “Detection of change is defined as the process of demonstrating that climate or a system affected by climate has changed in some defined statistical sense, without providing a reason for that change. An identified change is detected in observations if its likelihood of occurrence by chance due to internal variability alone is determined to be small, for example, <10%.”

Attribution: “Attribution is defined as the process of evaluating the relative contributions of multiple causal factors to a change or event with a formal assessment of confidence.”

Both steps rely on statistical analysis. Detection focuses on whether changes are significant enough to stand out from random variation regardless of cause. Attribution involves comparison of observed events to model-generated counterfactuals. Since experimentation on the climate is not possible, attribution requires statistical inference to assess how much human activities, such as GHG emissions, versus natural factors, like volcanic eruptions, contribute to observed changes. Attribution methods assume all external and internal drivers of the system are known and represented.

There are ongoing scientific debates around attribution methods, especially for attributing extreme weather events to climate change. The IPCC has long cautioned that methods to establish causality in climate science are inherently uncertain and ultimately depend on expert judgement. The Fourth Assessment Report: The Physical Science Basis (Hegerl et al., 2007) explained it as follows:

‘Attribution’ of causes of climate change is the process of establishing the most likely causes for the detected change with some defined level of confidence... unequivocal attribution would require controlled experimentation with the climate system. Since that is not possible, in practice attribution of anthropogenic climate change is understood to mean demonstration that a detected change is ‘consistent with the estimated responses to the given combination of anthropogenic and natural forcing’ and ‘not consistent with alternative, physically plausible explanations of recent climate change that exclude important elements of the given combination of forcings’ (IPCC, 2001)... The approaches used in detection and attribution research described above cannot fully account for all uncertainties, and thus ultimately expert judgement is required to give a calibrated assessment of whether a specific cause is responsible for a given climate change.

The Fifth Assessment Report Working Group II makes the following statement:

¹ Note that the IPCC definition of “climate change” allows for both natural and human causes. This differs from the UNFCCC definition (and common usage), where the term is limited to human causes.

(Cramer et al., 2014):

“Two broad challenges to the detection and attribution of climate change impacts relate to observations and process understanding. On the observational side, high-quality, long-term data relating to natural and human systems and the multiple factors affecting them are rare. In addition, the detection and attribution of climate change impacts requires an understanding of the processes by which climate change, in conjunction with other factors, may affect the system in question.”

Because of the complexity of the causal chains in the climate system, investigation of these relationships is exceptionally challenging.

9.2 Attribution methods

The Intergovernmental Panel on Climate Change (IPCC) employs several attribution methods to assess the causes of observed climate changes, distinguishing between natural and human-induced factors. Below is a concise description of the key methods that have been used by the IPCC:

Optimal Fingerprinting uses linear regression to explain variations in observed climate data as a weighted sum of climate model simulations run with and without anthropogenic forcings. The data used in the regression model are weighted to try to minimize the influence of random noise and the estimation method is chosen to take account of climate model error.

Time Series Analysis exploits statistical differences between anthropogenic forcing and natural variability to see which dominates observed temperatures, and also uses variations in the timing of changes to determine if causal dependence across data series can be inferred.

Process-Based Attribution focuses on understanding the physical mechanisms behind observed changes. This approach combines observations, climate models, and theoretical understanding to attribute changes in specific processes to forcings. This approach is often used for regional climate phenomena, such as monsoon changes or polar amplification

Extreme Event Attribution assesses in the role of human influence in the likelihood of occurrence or intensity of extreme weather events (e.g. heat waves, droughts). Methods include:

- Probabilistic Event Attribution uses large ensembles of climate model simulations to compare observed events to model-generated counterfactuals
- Storyline Approach examines the physical processes driving an event and evaluates how anthropogenic forcings may have modified those processes

9.3 Attribution of global warming

Attribution statements for global warming in the three most recent IPCC Assessment reports are:

AR4: “Most of the observed increase in global average temperatures since the mid-20th century is *very likely* due to the observed increase in anthropogenic greenhouse gas concentrations.” (IPCC, 2007)

AR5: “It is *extremely likely* that more than half of the observed increase in global average surface temperature from 1951 to 2010 was caused by the anthropogenic increase in greenhouse gas concentrations and other anthropogenic forcings together. The best estimate of the human- induced contribution to warming is similar to the observed warming over this period.” (IPCC, 2013)

AR6: “The *likely* range of total human-caused global surface temperature increase from 1850–1900 to 2010–2019 is 0.8°C to 1.3°C, with a best estimate of 1.07°C. It is *likely* that well-mixed GHGs contributed a warming of 1.0°C to 2.0°C, other human drivers (principally aerosols) contributed a cooling of 0.0°C to 0.8°C, natural drivers changed global surface temperature by –0.1°C to +0.1°C, and internal variability changed it by –0.2°C to +0.2°C. It is *very likely* that well-mixed GHGs were the main driver of tropospheric warming since 1979.” (IPCC, 2021)

The AR4 and AR5 attribution statements reference the warming since the mid-20th century, the period when greenhouse gas emissions began rapidly increasing. The words “most” and “more than half” are deliberately imprecise, potentially ranging from 51 to 99% of the warming – presumably this imprecision is to account for structural uncertainties such as natural internal variability. The confidence level increases from *very likely* to *extremely likely* from AR4 to AR5. The structure of the attribution statement in the AR6 is fundamentally different, referencing the warming to the period 1850-1900. The AR6 attribution statement is more precise numerically, but with a lower level of confidence at “likely” – the AR6 attributes essentially all the warming to increases in greenhouse gases. The most confident statement from the AR6 relates to the tropospheric warming since 1979, using the words “main driver” and “*very likely*.”

There are three areas of substantive criticism of the IPCC’s assessment of the causes of the recent warming: inadequate assessment of natural climate variability, inappropriate statistical methods, and substantial discrepancies between models and observations. The last is discussed in Chapter 6, while this chapter discusses the first two factors. All of these criticisms are relevant to the IPCC’s policy-informing attribution of the recent warming, which also underpins extreme event attribution

9.3.1 Natural climate variability

IPCC AR6 states that natural external drivers since 1850-1900 have changed global surface temperature by –0.1°C to +0.1°C, and internal variability has changed it by –0.2°C to +0.2°C – on average having essentially no net impact on the warming since 1850-1900. This minimal contribution of natural variability has been disputed by a number of publications that question the magnitudes of solar variability and internal variability from the large-scale ocean circulations (R Connolly et al., 2021; W Soon, 2023).

If the Equilibrium Climate Sensitivity to CO₂ is low (Chapter 5), then natural climate variability becomes more important in the attribution of the recent warming. Further, if natural variability is

higher, then estimates of the Equilibrium Climate Sensitivity from the historical period would be lower (Scafetta, 2023).

Solar variability

IPCC AR5 concluded that the best estimate of radiative forcing due to Total Solar Irradiance (TSI) changes over the period 1750–2011 was 0.05 W/m^2 (Myrhe et al., 2014). IPCC AR6 acknowledges a much larger range of estimates of changes in TSI over the last several centuries, stating that the TSI between the Maunder Minimum (1645–1715) and the second half of the twentieth century increased by $0.7\text{--}2.7 \text{ W/m}^2$, a range that includes both low and high variability TSI data sets (Gulev, 2021). However, the recommended forcing dataset for the CMIP6 climate model simulations used in AR6 for attribution studies averages two data sets with low solar variability (Matthes, 2017).

While AR6 shows a substantially greater solar impact than does AR5, the overall impact on the climate was assessed to be small compared to anthropogenic forcing of climate change. However, the impact of solar variations on the climate is uncertain and subject to substantial debate – something that is not evident from the IPCC assessment reports (Lockwood, 2012; Connolly et al., 2021).

Exactly how TSI has changed over time has been a challenging problem to resolve. Since 1978, there have been direct measurements of TSI from satellites. However, the data exhibit non-negligible inconsistencies, and interpreting any multi-decadal trends in TSI requires comparisons of observations from overlapping satellites. There are several rival composite TSI datasets, disagreeing as to whether TSI increased or decreased during the period 1986–96 (the ACRIM gap; see Chapter 4). Further, the satellite record of TSI is used for calibrating proxy models, whereby past solar variations are inferred from sunspots and cosmogenic isotope measurements (Velasco Herrera et al., 2015).

There is substantial evidence for high solar activity in the second half of the 20th century (starting in 1959) and extending into the 1990's, before a decline in the early 21st century; this period is often termed the “Modern Maximum.” (Chatzistergos et al., 2023; Solanki et al., 2004; Usoskin et al., 2007). However, some scientists have concluded that it is not possible to be confident of any multi-decadal trend in TSI (Schmutz, 2021).

As a result of this uncertainty, some reconstructions for past values of TSI (since 1750) have low variability, implying a very low impact of solar variations on global mean surface temperature, whereas datasets with high TSI variability can explain more than 70% percent of the temperature variability since preindustrial times (Scafetta, 2013; Stefani, 2021). Hence, the choice of which TSI satellite record used in an analysis can substantially influence how much climate change is attributed to human versus natural forcings.

There is growing evidence that other aspects of solar variability, which are referred to as solar indirect effects, amplify TSI forcing or are independent of TSI forcing. Scafetta et al. (2023) suggests that ~80% of solar influence on climate may stem from non-TSI mechanisms. Candidate processes include: solar ultraviolet changes; energetic particle precipitation; atmospheric-electric-field effect on cloud cover; cloud changes produced by solar-modulated galactic cosmic rays; large

relative changes in the magnetic field; and the strength of the solar wind. Solar indirect effects are not included in climate models, although indirect methods of estimating these effects suggest significant influence. However, claims of non-TSI mechanisms influencing climate are uncertain and debated.

Natural variability of large-scale ocean circulations

Variations in global mean surface temperature are linked to recurrent large-scale variations in ocean circulation patterns. These circulation patterns include the Atlantic Multidecadal Oscillation (AMO), the Pacific Decadal Oscillation (PDO) and the El Nino-Southern Oscillation (ENSO). These circulation patterns influence ocean heat uptake and heat distribution, and also influence atmospheric circulation patterns and cloud distributions. There is some debate as to whether these variations are strictly internal to the climate system, or whether this variability can have a solar/astronomical origin or can be influenced by large volcanic eruptions.

While climate models simulate the large-scale ocean circulations and internal climate variability, the simulated magnitude in the multi-decadal band is too low in most models relative to observations, and the phasing of the variability in long-term climate simulations is not synced with the actual, observed climate variations (Kravtsov et al. 2024). Averaging multiple simulations from climate models effectively averages out the internal variations, leaving only the forced climate variability (e.g., CO₂ forcing). With most of the modern warming beginning in the late 1970's, the recent 50-year warming is on the same time scale as the multi-decadal oscillations of the AMO and PDO.

Here are summary statements from the IPCC AR5 and AR6 reports:

“Decadal variability in the Pacific, associated with the PDO or IPO, contributes significantly to regional and global temperature trends, but the relative contributions of internal variability and external forcing are difficult to disentangle in CMIP5 simulations.” (IPCC, 2013)

"Since AR5, there has been increased understanding of the role of internal variability, such as ENSO, PDO, and AMO, in modulating regional climate trends. However, limitations in simulating the exact timing and amplitude of these modes in CMIP6 models contribute to uncertainties in attributing observed changes to anthropogenic forcing (high confidence)." (IPCC, 2021)

The amplitude of the peak-to-trough impact of the multi-decadal oscillations on global temperatures has been assessed by the IPCC AR6: “The likely range of change due to internal variability is -0.2°C to +0.2°C (IPCC, 2021).” This implies a trough-to-peak change of 0.4°C. Over many centuries, any global temperature changes from the troughs and peaks will cancel out, with little to no net impact.

However, with a nominal timescale of 60-80 years for oscillations such as the AMO and PDO, the timing of the peaks and troughs can be confused with the secular trend. This becomes very relevant for attributing the warming for the 50 years since 1975, during which most of the warming has occurred. Even if climate models have the correct amplitude of the multidecadal oscillations, the

timing of the peaks and troughs is not adequately simulated, with each model and individual ensemble simulating a different phasing. Once the simulations of the ensemble members and different models are averaged, the natural internal variability contribution is averaged out, effectively cancelling the role of natural internal variability in the attribution process.

The Great Pacific Climate Shift of 1976-1977 was a notable climatic event characterized by an abrupt change in the North Pacific Ocean's atmosphere-ocean system that interacted with global climate patterns. This shift is closely associated with the Pacific Decadal Oscillation (PDO) that oscillates between warm and cool phases over decades. The 1976 shift marked a transition from a predominantly negative (cool) PDO phase (1947–1976) to a positive (warm) phase (1977 through 2000), with significant implications for global and regional climate patterns including the frequencies of El Niño and La Niña events. The Great Pacific Climate Shift coincided with the beginning of a period of accelerated global warming (REF TO A FIG OF GLOBAL TEMP ANOMALIES ELSEWHERE IN DOC) When the Great Pacific Climate Shift is accounted for in climate attribution analyses since 1950, it has been found that 40 percent or more of the warming in the second half of the 20th century was caused by natural internal variability (McLean et al., 2009; Tung and Zhou, 2013; Chylek et al., 2016; Scafetta, 2021).

9.3.2 Optimal fingerprinting

Optimal fingerprinting is a statistical technique introduced by Allen and Tett (1999) that compares observed climate data to climate model simulations to identify patterns (or "fingerprints") associated with human or natural forcing. It involves taking a vector of observed climate changes, such as warming rates in locations around the world, and decomposing them into a weighted sum of "signals", which are analogues to the observations generated by climate models with different types of forcings. The weights are chosen using a regression method called Total Least Squares. The analysis commonly uses just two signals, one generated by models using only anthropogenic forcings and one using only natural forcings. If the estimated weighting coefficient attached to a signal is significantly different from zero, then that signal is said to be "detected". If it is close to 1.0, then the model generating the signal is said to be consistent with observations. If it is less than 1.0, then the model signal for that forcing is too strong and needs to be scaled down, and vice-versa. Both the observed data and the signals are weighted using a model-generated estimate of patterns of randomness in the climate system so as, in principle, to put maximum weight on regions where natural variability is minimized.

Optimal fingerprinting is the primary tool for attribution in the climate literature. Studies applying it have been cited thousands of times, and it has been prominently featured by the IPCC since the 2001 Third Assessment Report. One of its inherent weaknesses is that results depend on assumptions about the accuracy of climate models, especially regarding their representation of natural variability (IPCC AR5 Ch 10.2.3).

Additionally, a series of papers by McKittrick (McKittrick 2022a, 2022b, 2023, 2025) has challenged the optimal fingerprinting method, arguing that it is inherently unreliable and that commonly used practices in econometrics can provide more valid results. Statistical theory requires that for regression models to yield unbiased coefficients, a set of assumptions called the Gauss-Markov conditions must hold. McKittrick (2022a) argued that the Allen and Tett (1999)

methodology violates the Gauss-Markov conditions, leading to potentially biased and inconsistent fingerprinting coefficients, undermining the reliability of the method. Chen et al. (2023) confirmed this analysis and argued that the method could yield unbiased results but only under very stringent assumptions. McKittrick (2022b) and (2023) raised a further concern that climate scientists—virtually alone among scientific disciplines—have used an estimation method called Total Least Squares (TLS) to estimate anthropogenic greenhouse gas signal coefficients, despite its tendency to be unreliable unless some strong assumptions hold that in practice are unlikely to be true. Under conditions which easily arise in optimal fingerprinting, TLS yields estimates with large positive biases. Thus, any study that has used TLS for optimal fingerprinting without verifying that it is appropriate in the specific data context has likely overstated the result.

McKittrick (2025) presented an empirical example comparing the results of conventional optimal fingerprinting against methods drawn from mainstream econometrics which are known to be valid for the specific application of signal detection. While the IPCC optimal fingerprinting method yields an anthropogenic signal coefficient close to 1.0 on a global temperature data set spanning 1900 to 2010, consistent estimation yields a coefficient around 0.4, which rises to about 0.65 on data spanning 1980 to 2010, implying the model response to greenhouse gases needs to be scaled down by about half to optimally match observations. The natural forcing signal coefficient, by contrast, is between 2.0 and 4.0, implying the climate model signals of natural forcing need to be scaled up two-to four-fold to match observed climate change. The fingerprinting coefficients estimated in McKittrick (2025), when used to scale the average sensitivity of the climate models used to generate the forcing signals in his data set, imply a Transient Climate Sensitivity of 1.4°C, which matches the estimate by Lewis (2022) using a different estimation method and multiple independent data sets.

While these analyses do not prove that all of the results from using the IPCC optimal fingerprinting method are wrong, it does show that the basis on which they were believed to be correct is non-existent – hence reducing confidence in the results.

9.3.3 Time series methods

The IPCC (AR5 WGI 10.2.2) drew attention to alternative approaches of assessing causality that emerged from the time series econometrics literature. They have the advantage of not depending on assumptions about the accuracy of climate models, but their disadvantage is they depend on assumptions about the data generating process underlying climate and forcing data that are not straightforward to test. The methods, now referred to as climate econometrics, use the tools of unit root testing, Granger causality and cointegration analysis, all of which are familiar in economics and finance and which are slowly being adopted in climate science. Time series analysis methods hold out the possibility of determining whether anthropogenic or natural forcings are the primary drivers of climate change without requiring the use of climate models, although key questions remain unsettled (e.g. Dergiades et al. 2016, Balcombe et al. 2019, Dagsvik et al. 2020, Razzak 2022, Dagsvik and Moen 2023).

Granger causality modeling is a tool for determining directions of influence in data series that move together. “Granger causality” is a statistical, not a physical, concept. If knowing the current value of one variable significantly improves the forecast accuracy of another variable we can infer a causal connection exists; this is called Granger causality. The modeling tools, called

vector autoregression, measure direct impulse-response patterns and feedbacks. An application to the well-known Vostok ice core data revealed an error by Al Gore in his documentary *An Inconvenient Truth*. Gore showed the data and drew attention to the coherence of temperature and CO₂ changes over a 440,000 year span, which he asserted was due to CO₂ driving temperature changes. But temperature changes can also affect atmospheric CO₂ levels. Davidson et al. (2015) examined the series and found that temperature Granger causes CO₂ but not the reverse. In other words on the time scales represented in the Vostok data the coherence in the series is primarily due to the influence of temperature on CO₂ levels not the feedback going from CO₂ to temperature.

In summary, the main statistical methods for attributing causation in climate data are optimal fingerprinting and time series analysis. Applications of the Allen and Tett (1999) optimal fingerprinting method dominate the attribution literature and have underpinned past IPCC conclusions, but results depend on the accuracy of climate models and the method has recently been criticized as inherently biased. Time series methods do not depend on climate models but require assumptions of their own and have generated results that have thus far not converged on a consensus.

9.4 Attribution of climate impact drivers

The IPCC (Ranasinghe et al. 2021) defines “climate impact drivers” or CIDs as “physical climate system conditions (e.g., means, events, extremes) that affect an element of society or ecosystems.” Hence CIDs are those features of the weather and climate system of primary interest when assessing the impacts of climate change since they potentially affect humans and the natural world. For instance, under the heading “Heat and Cold” CIDs are identified as mean air temperature, extreme heat, cold spells and frost. The IPCC also points out that CIDs are not necessarily harm-related: depending on the system in question they can be detrimental, neutral, beneficial or a combination.

Table 12.12 in Ranasinghe et al. (2021, p. 1856) summarizes the AR6 assessment of whether a signal of attributable anthropogenic influence has emerged across all major CIDs. One of the themes of this chapter is that attribution methods used by the IPCC tend to overstate the anthropogenic influence and understate the role of natural variability. Nonetheless a striking feature of that summary table is how few CIDs exhibit an anthropogenic signal sufficient to distinguish them from natural variability. The reported findings are listed in Table 9.1 which adapts IPCC AR6 Table 12.12.²

Climate Impact Driver Type	Climate Impact Driver Category	Already Emerged in the Historical Record?	Emerging by 2050 in Most Extreme CO2 Emissions Scenario?	Emerging by 2100 in Most Extreme CO2 Emissions Scenario?
Heat & Cold	Average air temperature	YES in most regions	YES	YES
	More heat extremes	YES in most regions	YES in land regions	YES
	Fewer cold extremes	YES in a few regions	YES in many regions	YES
	Less frost	NO	NO	NO

² We have separated polar sea ice into Arctic and Antarctic categories for clarity, and removed ground-level CO₂ as a CID since claiming anthropogenic signal due to CO₂ emissions is a tautology.

Wet & Dry	Average Precip. (Increase or Decrease)	NO	YES (incr) YES (decr)	YES (incr) YES (decr)
	River flooding	NO	NO	NO
	Heavy precip & pluvial flood	NO	NO	YES in a few regions
	Landslide	NO	NO	NO
	Aridity	NO	NO	NO
	Hydrologic Drought	NO	NO	NO
	Agricultural & ecological drought	NO	NO	NO
	Fire weather	NO	NO	NO
Wind	Average wind speed	NO	NO	NO
	Severe wind storm	NO	NO	NO
	Tropical cyclone	NO	NO	NO
	Sand and dust storm	NO	NO	NO
Snow and Ice	Snow, glacier & ice sheet	NO	YES in a few regions	YES Arctic snow
	Permafrost	YES	YES	YES
	Lake & river ice	NO	YES	YES
	Arctic sea ice	YES	YES	YES
	Antarctic sea ice	NO	YES	YES
	Heavy snowfall and ice storm	NO	NO	NO
	Hail	NO	NO	NO
	Snow avalanche	NO	NO	NO
Coastal	Relative sea level	NO	YES	YES
	Coastal flood	NO	NO	NO
	Coastal erosion	NO	NO	NO
Open Ocean	Average ocean temperature	YES	YES	YES
	Marine heat wave	NO	NO	NO
	Ocean acidity	NO	YES	YES
	Ocean salinity	YES	YES	YES
	Dissolved oxygen	YES (Pacific & S. Ocean)	YES	YES
Other	Air pollution weather	NO	NO	NO
	Solar or IR radiation at surface	NO	NO	NO

Table 9.1. IPCC AR6 summary of the probable emergence of an anthropogenic signal above natural climate variability for all global or regional “climate impact drivers” (CIDs) of concern for humans and ecosystems in response to increasing atmospheric greenhouse gas concentrations (primarily CO₂). Source: Table adapted from report of Working Group I, Table 12.12). Red = high confidence; yellow = medium confidence; green = no anthropogenic signal detectable above natural variability (50% confidence).

Several patterns stand out. First, out of the 34 weather impact categories an anthropogenic signal is asserted with *high confidence* in only four, and with *medium confidence* in a further four. For the rest the IPCC does not claim to have detected anthropogenic drivers. Of the four *high confidence assertions*, two are for changes in average temperatures (air and ocean) hence are not measures of extreme weather. Also two of the four *medium confidence* assertions are related to ocean chemistry and thus are likewise not related to extreme weather. The IPCC does not assert a human influence on many non-temperature weather features such as wind, precipitation, flooding, drought etc.

Second, as shown in columns 2 and 3 the IPCC expects very few such signals to emerge this century even under the most extreme forcing scenario. As we discuss in Chapter 4 the RCP8.5 scenario is an implausible high-end storyline, it is not a “base case” or business-as-usual

projection. Yet even still most weather impacts are not expected to exhibit an anthropogenic signal this century. As we discussed in Chapter 7 natural variability dominates patterns of extreme weather systems and simplistic assertions of trend detection are frequently undermined by regional heterogeneity and trend reversals over time.

A point we emphasized in Chapter 7 was that, despite commonly-heard claims that all types of extreme weather are getting worse due to human activity, few significant trends in most weather types can be detected due to high levels of natural variability over long time scales. Table 9.1 makes the related point that, again contrary to popular belief, attribution of changes in most extreme weather types to human influence is not currently possible. Taking wind as an example, the IPCC claims that an anthropogenic signal has not emerged in average wind speeds, severe windstorms, tropical cyclones or sand and dust storms, nor is one expected to emerge this century even under an extreme emissions scenario. The same applies to drought and fire weather.

9.5 Extreme event attribution (EEA)

Examining the IPCC's treatment of extreme weather and climate event attribution more broadly, the AR6 provides an ambiguous assessment of the role of anthropogenic warming that differs between chapters. Chapter 11 of WG1 states (Seneviratne et al., 2021):

“Evidence of observed changes in extremes and their attribution to human influence (including greenhouse gas and aerosol emissions and land-use changes) has strengthened since AR5, in particular for extreme precipitation, droughts, tropical cyclones and compound extremes (including dry/hot events and fire weather). Some recent hot extreme events would have been extremely unlikely to occur without human influence on the climate system.”

By contrast, as noted, Chapter 12 of WG1 (Table 12.12) paints a different picture – presumably, the expert judgment of different groups of authors for the two chapters came to different conclusions (Ranasinghe, 2021):

- High confidence in an increase in extreme heat events in tropical regions where observations allow trend estimation and in most regions in the mid-latitudes, medium confidence elsewhere
- Medium confidence in a decrease in extreme cold events in Australia, Africa and most of northern South America where observations allow trend estimation
- No evidence of emergence in the historical period of a change in river floods, heavy precipitation, drought, fire weather, severe wind storms, and tropical cyclones

While the overall issue of detecting changes in extreme weather events and their attribution remains ambiguous, most of the activity in this area relates to the attribution of single extreme weather events. The most prominent effort is the World Weather Attribution (WWA; worldweatherattribution.org), which is an international research initiative that focuses on extreme event attribution analyzing how climate change influences the likelihood and intensity of extreme weather events. The approach used by the WWA runs large ensembles of regional climate models to compare the event in today's climate, versus a pre-industrial counterfactual climate without human-caused warming.

WWA plays a prominent role in linking extreme weather to climate change and its press releases attract considerable public and policy discussions. However, the WWA's tendency to promote non-peer-reviewed findings, funding ties, open admission that they shape their analyses to serve purposes of litigation and other methodological challenges have sparked controversies, with critics questioning the robustness and impartiality of its conclusions (Pielke Jr. 2024). Despite these issues, WWA's work continues to shape climate science and media narratives. Technical criticisms of the approach include: neglect of a formal detection process; an implicit assumption that 100% of the post-industrial warming is caused by CO₂; and failure to adequately account for natural internal climate variability.

Because EEA is relatively new many basic methodological issues have yet to be settled in the expert literature. An important challenge is the lack of data. Extreme events are by definition rare. Many analyses of extreme event types (including the US National Assessment Reports) only evaluate data since 1950 or 1970. However, as emphasized by Chapter 7, many of the worst extreme weather and climate events in U.S. history occurred prior to the first half of the 20th century including in the early 19th century. And if paleoclimate reconstructions are considered, it becomes very difficult for an event to pass the detection thresholds of exceeding what is expected from natural variability, particularly if a reasonably sized geographic region is considered.

Another challenge is defining the event under study. There is a longstanding literature in statistics and econometrics on the challenge of analyzing data with outliers. The issue arises because a data series establishes a probability distribution defining the expected range of observations. If an outlier is observed it might indicate that the underlying process giving rise to the data distribution has changed (which in the weather context would mean a climatic change has been detected) or that the underlying process has multiple regimes each with a different probability distribution, in which case observing an outlier simply means we were temporarily in a different regime, but the system itself was unchanged. If a time series contains only a single outlier event at the end of the series it is not possible to determine which model is the correct one (Chen and Liu 1993). For instance, there might be an "ordinary" weather regime that yields a distribution of summer daytime highs in a particular coastal region, and a second "heatwave" regime that kicks in when an inland blocking event occurs, which yields a temperature distribution centered 15°C higher than the first one. A day with temperatures 13°C above normal would either be an extreme heat anomaly under the first regime or a somewhat cool event under the second, and we have no way in this case of knowing on statistical grounds which view is correct.

Visser and Petersen (2012) and Sardeshmukh et al. (2015) both point out that different distributions may fit observed data equally well but yield very different implications about the likelihood of a specific weather event. Visser and Petersen argue that, in view of the deep uncertainties of extreme weather analysis drawing a connection between individual events and global climate change should be avoided. Furthermore the existence of an outlier at the end of a data series poses the problem that estimates of the event probabilities will be biased whether the outlier is included or excluded (Barlow et al. 2020). Methods to eliminate the bias have not yet been established, leading some experts (e.g. Miralles and Davison 2023) to argue that in settings in which a data series contains a single extreme event at the end, estimation of a return period for the extreme event will be so biased and uncertain it should be avoided altogether.

In spite of these concerns, the U.S. is presently considering something like the WWA, which is being investigated by a NASEM Panel on Attribution of Extreme Weather and Climate Events and their impacts (NASEM, 2025).

A case study from a recent high impact extreme events in the U.S. is provided to illustrate the challenges and ambiguities in attributing the frequency and intensity of extreme weather events to human-caused warming.

9.4.1 Case study – 2021 Western North America heat wave

The 2021 Western North America heat wave was an extreme heat wave that affected much of Western North America in late June 2021. In particular, surface temperature records were set in Portland, OR (116°F; previous record 107°F) and Seattle, WA (108 °F; previous record 103°F) (Mass et al., 2024).

The WWA team garnered international headlines for their analysis and provided the following attribution statements (WWA, 2021; Philip et al., 2022):

- Based on observations and modeling, the occurrence of this heatwave was virtually impossible without human-caused climate change.
- The event is estimated to be about a 1 in 1000-year event in today's climate.
- The event would have been at least 150 times rarer without human-induced climate change.
- This heatwave was about 2°C hotter than it would have been if it had occurred at the beginning of the industrial revolution (when global mean temperatures were 1.2°C cooler than today).

But an important caveat to the first claim is that other researchers concluded, based on historical weather data, that while a heat wave of the magnitude observed was indeed virtually impossible without anthropogenic climate change, it was also virtually impossible *with* climate change. Bercos-Hickey (2022) noted “these temperatures were virtually impossible under any previously experienced meteorological conditions, with or without global warming.” McKinnon and Simpson (2022) stated “the most likely explanation remains that the weather event itself was ‘bad luck.’” The 2023 Oregon Climate Assessment (Fleischman 2023) concluded that the heat dome would have formed even without climate change and “There is no evidence that the highly unusual combination of weather features that drove the heat dome were made more likely by climate change, and climate models do not project an increase in the frequency of high-pressure ridges over the Pacific Northwest” (Fleischman 2023 p. 49).

Mass et al. (2024) summarizes the proximate sequence of compound events leading to the heat wave. There was a record-breaking midtropospheric ridge over the Pacific Northwest, forced by a tropical disturbance in the western Pacific. This produced record-breaking midtropospheric temperatures, strong subsidence in the lower atmosphere, low-level easterly flow that produced downslope warming on regional terrain and the removal of cooler marine air, and an approaching low-level trough that enhanced downslope flow. The event occurred at a time of maximum solar insolation, and drier-than-normal soil moisture. Using a storyline approach, Mass et al. assessed that there is no trend in drought and dry soils in the Pacific Northwest; there is no evidence of